Why and How to Renew Evolutionary Biology for Worldwide Use in One Health

A Detailed and Integrated Case for Progressive Change

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Nectar producing *Corymbia ficifolia* and nectar feeding pollinator, *Apis mellifera*.

A celebration of evolvable mutualism and ecosystem health.

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'Humanity is exalted not because we are so far above other living creatures, but because knowing them well elevates the very concept of life' (Edward O. Wilson in *Biophilia*, 1984. Biophilia infers an innate affection of humankind for life and lifelike processes.

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Abstract

Evolution theory (the Theory of Evolution by Natural Selection) and evolutionary biology bear upon all aspects of the biology and has had tacit application within One Health where it has provided important insights into the spectrum of health, ill-health and disease in animals. Evolution theory has enlightened host-pathogen and host-parasite interactions, the operation of immune responses, and resistance to antimicrobials, anthelmintics and pesticides. One Health can benefit from a more explicit and disciplined application of evolutionary biology. Evolutionary biology has been advanced as a 'basic scientific discipline' for medicine and the same can apply to One Health-Global Health-Planetary Health and its component parts, which extend to veterinary medicine, agriculture and natural resources management. Contemporary challenges confronting One Health include epidemic and pandemic diseases like COVID-19 and influenza. A proposal is made for how evolution theory can be guided by cell theory and merged with germ theory and thus enlighten One Health responses to these persistent hazards.

The efficacy of evolution theory in One Health depends upon strict attention to the explicit nature of laws, theories, principles and hypotheses in the practice of science and the vehicle for renewing aspects of evolutionary biology according to present-day advances in science and biology is an ontology as employed in information technology and computing. Ontologies are required to be stringently and diagrammatically structured with specifically defined language in order to create interoperability or the ability to exchange and use information for reasoning and decision-making. The ontology in mind is structured according to a concept hierarchy with the phenomenon of evolution or Darwin's 'descent with modification' as the superordinate concept. Precising definitions are constructed as a means for making the substance of the ontology intelligible, universally accessible and open to modification in the light of new knowledge.
Keywords: Evolution, One Health, Biology, Systems Thinking, Sustainability, Ecosystem Management, Comparative Medicine.

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Preamble

Summary

The scope and purpose of this report is summed up in the title *One Long Argument on How and Why to Renew Evolutionary Biology for Worldwide Use in One Health*. The report is prompted by some conspicuous and detrimental misconceptions that have had currency in evolutionary biology and which must be addressed to allow the sound communication of this sub-discipline within One Health and to capture its full value for understanding the dynamics of infectious diseases like those caused by influenza and coronaviruses in both people and animals. Foremost among the detrimental misconceptions encumbering the utility of evolutionary biology are linguistic issues and destructive misconceptions such as the failure to appreciate the nature of scientific laws, principles, theories and hypotheses. Figurative language, polysemy (the use of words with with many possible meanings) and argumentative and promotional discourse in the literature around evolution have often overshadowed the coherent exposition of facts, concepts and reasoning required for effective action in One Health. These shortcomings give a free hand for the proposed renewal of evolutionary biology to fit the purposes of One Health and with its particular emphasis on physiology as the branch of biology that aims to understand the mechanisms of living things.

One Long Argument is a phrase used by Darwin to describe his detailed aggregation of evidence for natural selection as the process driving evolution or 'descent with modification'. The phrase is apt for the present report because renewal of aspects of evolutionary biology for One Health, given its historical encumbrances, requires a detailed account of the past history and present status of this sub-discipline in the general context of contemporary biology, science and public affairs and a consideration of how evolutionary biology can extend to life forms such as viruses and prions. A reckoning of present-day opportunities for the universal and intelligible communication of evolution and evolutionary biology in the face of language barriers is a key component of the present *One Long Argument* and the ontology employed as an agency in information technology became self-evident as a means to the ends in mind. Ontologies require precising definitions or for their component parts. Precising definitions aim at reducing the vagueness of terms and concepts

The process of renewing aspects of evolutionary biology for efficacy within One Health occurs in three steps. These three steps are preceded by some preliminaries including an explanation of the nature of One Health (its values, what it is and what it does) and a description of the methods used to construct the report as a systematic review that is open to constructive feedback. The report ends with a recapitulation of the three steps towards renewal followed by an exposition of the product of renewal and an example of its application in foreshadowing the emergence of infectious diseases. A foundational assumption is that the fundamentals of evolution theory were presciently and demonstrably captured by Darwin in *Origin of Species* and were subsequently reiterated by Wallace (1889). Darwin's fundamentals of the theory of evolution by natural selection are reiterated in the light of current biological knowledge remembering that theories, in the sense defined for science,

provide landmarks for old and new knowledge and require continual refinement in order to maintain their usefulness. The breadth of coverage and the extent of detail required to address controversies within the history of evolutionary biology and to prepare for the proposed ontology makes this *One Long Argument* a resource of well grounded information, knowledge and ideas that can inform further and more specific reflections upon how evolutionary biology may enhance One Health.

Chapter 2 sets out the first or scene-setting step towards renewing aspects of evolutionary biology for efficacy within One Health of the report and begins by explaining the beneficial relationship between evolutionary biology and One Health. Issues such as the relationship between aspects of philosophy are religion are then explored. Present-day mainstream Christianity and Islam endorse evolution theory for its humanitarian potential and recognise its compatibility with their religions. Chapter 2 then moves to the case for using an ontology, a particular conceptual framework employed in information technology, to explore how evolution theory can be formulated for practical application across the entire One Health. In short, an ontology is an ordered structure of interrelated and purposefully defined concepts that underpins software function. Ontologies require strict attention to concept hierarchies and precising definitions. Then follows some thoughts on the linkages between One Health and (i) international affairs, (ii) economics, (iii) ethics and the practice of science, (iv) communication and universal access to knowledge, (v) translation and extension of knowledge, (vi) risk analysis and hazard characterisation and (vii) reciprocity and knowledge sharing within and between One Health and the field of evolutionary biology.

Chapter 3 covers the second part of the process for renewing aspects of evolutionary biology and gives a perspective from the lessons of history. One such lesson is the legacy of misunderstanding what theories are in the practice of science and how this misunderstanding constitutes a critical flaw in past renditions of the theory of evolution by natural selection. The words ‘theory’, ‘nature’ and ‘natural’ plus 34 other words were explored in current and past dictionaries to determine their different meanings and dates of initial usage. The results were employed in a process of textual analysis as set out in the materials and methods to document their problematical past usage.

Chapter 3 concludes with an explanation of how and why Darwin’s *Origin of Species* captured the enduring essence of the theory of evolution by natural selection which can be renewed according to present day knowledge, opportunities for communication and precising definitions for concepts such as fitness, adaptation and species. Chapter 4 covers the third part of the renewal process and sets out the opportunities from information technology (IT) particularly ontologies and concept hierarchies that can facilitate the management of present-day biological knowledge and its advances. Advances in biology are then identified and elaborated and used to construct the precising definitions for terms and concepts employed in the proposed ontology.

Darwin’s example is followed and matters inspiring, guiding and shaping the present renewal are then ‘briefly recapitulated’ in Chapter 5 before the final act of assembling the ontology or type of conceptual framework for theory of evolution by natural selection from its explicitly defined component parts (Chapter 6). Recapitulation in Chapter 5 covers matters raised under the headings

of setting the scene (Chapter 2), the historical context for a renewed version of the theory of evolution by natural selection (Chapter 3) and pathways to renewed version of the theory of evolution by natural selection (Chapter 4). Recapitulation of these various interrelated matters in Chapter 5 is preceded by some thoughts about the word ‘renew’ which shapes the present effort.

The climax of the report in Chapter 6 assembles the ontology for expediting the utility and efficacy of evolutionary biology in One Health sets out the accompanying precising definitions for terms and concepts. The climax foreshadows an application of the ontology in marshalling the concepts and factors that lead to the emergence and re-emergence of infectious diseases and presenting them as concise and comprehensive formula, recipe or protocol assisted by an adaptation of the truth tables used in logic and information technology.

One Health, the focus of the report, has flourished since it was flagged by Schwabe (1984) in a statement paraphrased from Rudolph Virchow (b.1821, d. 1902): ‘Between animal and human medicine there is no dividing line, nor should there be. The object is different but the experience obtained constitutes the basis of all medicine’. One Health is currently depicted as an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems (World Health Organization, https://www.who.int/health-topics/one-health). According to the One Health High-Level Expert Panel (2002), the One Health approach seeks cooperation among different sectors, communities and disciplines across the whole of society to tackle threats like infectious disease epidemics, environmental degradation and climate change and to implement processes such as sustainable development that can meet communal needs for biosecurity, safe and secure food, water, energy, and air. One Health and its values provides a medium for consolidated action towards the common good by international organisations like the United Nations (UN), the World Health Organization (WHO), the Food and Agriculture Organization (FAO), United Nations Environment Programme (UNEP), the World Bank, the OECD (Organisation for Economic Co-operation and Development) and the World Organization for Animal Health (WOAH), by regional alliances and national governments and by civil society at large.

One Heath has practical aims and purposes, which are implemented by actions guided by the translation, extension, sharing and continuing renewal of knowledge and skills. Practical wisdom or the Greek ‘phronesis’ is an apt descriptor for the knowledge applying to One Health. It highlights the critical thinking and clinical or causal reasoning that has guided the development and sound application of medicine throughout history and which can apply across One Health. The theory of evolution by natural selection and evolutionary biology have had tacit application in the practical wisdom that applies in One Health and the pursuit of global health; for example, in understanding host-pathogen and host-parasite interactions, the operation of immune responses, and resistance to antimicrobials, anthelmintics and pesticides. One Health warrants a more explicit and disciplined application of evolutionary biology.

The present report comes with a full description of the methods used to achieve its ends and particularly to identify and characterise shortcomings within the literature around evolution. The

practice used in scientific articles has been followed where the materials and methods section sets out provide sufficient information for a prospective audience to understand and evaluate the work. Clarity around materials and methods opens the present report to critical feedback according to the organised scepticism that empowers science and gives it integrity (Merton, 1942). Methods used for systematic reviews have applied (PRISMA, 2000[1]). Systematic reviews allow for scrutiny of arguments, encourage reasoned refutation, and facilitate the progressive refinement of knowledge. Systematic reviews are underpinned by literature reviews, which identify, marshal and collate information on matters in question. The reference manager software, JabRef (https://www.jabref.org/), was used to collect and organise the bibliography for ease of access and retrieval and to facilitate writing. The use of reference management software like JabRef, Zotero, Mendeley and Endnote is recommended as a standard operational tool for practitioners in One Health.

Resources used to identify and then access relevant publications for the present report were Trove (a search engine of the National Library of Australia, https://trove.nla.gov.au), Project Gutenberg (https://www.gutenberg.org/), the Internet Archive (https://archive.org), the Open Library (https://openlibrary.org), Darwin Online (http://darwin-online.org.uk), the Biodiversity Heritage Library (https://www.biodiversityheritagelibrary.org) and Wikipedia https://wikipedia.org). Resources used to explore the current body of scientific literature were open access only and included PubMed from the National Library of Medicine in the US National Institutes for Health (https://pubmed.ncbi.nlm.gov), PubAg from the US Department of Agriculture National Agriculture Library (https://search.nal.usda.gov/discovery/), Google Scholar (https://scholar.google.com) and Semantic Scholar (https://www.semanticscholar.org). Information produced by government agencies, academics, businesses, and industries is an indispensable open resource. Access is available through general search engines such as Google (https://www.google.com) and Bing (https://www.bing.com) with links to relevant information from national and international agencies such as WHO (World Health Organization of the United Nations), FAO (Food and Agriculture Organization of the United Nations), WOAH (World Organisation for Animal Health), UNESCO (United Nations Educational, Scientific and Cultural Organization), OECD (The Organisation for Economic Co-operation and Development), the World Bank, and so on.

A process of textual analysis was employed to document the problematical past usage of a list of thirty four polysemous and semantically confused words such as ‘theory’, ‘nature’ and ‘natural’ and other words and phrases used figuratively as in ‘struggle for life’, ‘competition’, ‘trade-off’, ‘arms race’ and ‘selfish gene’. These words and phrases and were explored for their meanings and dates of origin in contemporary dictionaries (Encarta Dictionary of World English, 1999; The Shorter Oxford Dictionary, 2007; Webster’s New World Dictionary, 1986) and previous dictionaries (Webster’s American Dictionary of the American Language, 1828; A New English Dictionary on Historical Principles, 1888-1933) The process of textual scanning was enabled by the search function in two pdf readers (Foxit, https://www.foxit.com; and, Master PDF Reader, https://code-industry.net). Target words and phrases were tallied and allocated to their category of meaning in

[1] https://www.prisma-statement.org/

order to quantify inappropriate use, equivocal use and appropriate use of words and to set a course for further analysis and remediation.

Diagrams and tables are pivotal in the methodology used for the present report and have been a means for identifying issues, guiding literature searches and marshalling information and ideas as a preparation for writing and then as a resource for reflecting on the written text and reviewing its coverage and lucidity. Diagrams are visual presentations of information that help clarify, simplify and illustrate complex ideas and expedite intelligible communication. They include flowcharts, graphs, Venn diagrams, concept maps, block diagrams and conceptual frameworks that work by showing how different elements in a matter of interest mesh. In doing so, diagrams and the related idea of a schema make complex relationships more intelligible. Diagrams, tables and written texts complement one another to make communication more effective. Diagrams and tables provide reference points that make the written text more accessible and illuminating. A table based on the truth tables used in logic has been adapted to illustrate the interplay of causative factors in the emergence and re-emergence of infectious disease, especially those associated with RNA viruses which have high mutation rates and operate lateral gene transfer.

Part one of the three-part process of renewal (Chapter 2) begins with thoughts about the effective operation of One Health in the broad context of human affairs and the importance of clarity around the concept of theories in science as 'comprehensive explanations of aspects of nature that are supported by vast bodies of evidence such that they can be used to make predictions about natural events or phenomena that have not yet been observed' (National Academy of Sciences, 2008).

Perspectives from international affairs and economics overlap through the notion of global public goods, which are 'goods with benefits that extend to all people and generations' (Kaul and Mendoza, 2003). The tripartite collaboration between the FAO, WHO and WOAH (2017) epitomises the global public good and has matured into the One Health Action Plan (2022-2026) which recognises the importance of solidarity and that 'the combined knowledge, insights and technical capacities in food, agriculture, and human and animal health can generate strong synergies, which will yield more robust, effective and cost-efficient solutions to the complex problems facing the world today'. The scholarly values of knowledge or learning societies and open science (OECD, 1996; World Bank, 2002; UNESCO, 2005 and 2012; Stiglitz and Greenwald, 2014; WHO, 2020a; UNESCO, 2021) can realise this 'combined knowledge' as a global public good and the proposed ontology is a potential contributor to its practical application.

Perspectives from ethics and the practice of science also overlap in the settings for One Health. Norms of behaviour that guide the sound practice of science are suitably grounded in One Health by the Belmont principles of beneficence (doing good), non-maleficence (not doing harm), autonomy (respect for persons and their agency) and justice (the equitable distribution of beneficence and non-maleficence)(Beauchamp and Childress, 1994). These principles rule out the malign misinterpretations of theory of evolution by natural selection that allowed for eugenics and social Darwinism. Another ethical concern is the obligation of actors within One Health to maintain and

develop skills. Reliable knowledge comes from disinterested or objective reflection and analysis. Disinterestedness (D, putting truth and duty above self) joins three other matters to form the acronym CUDOS in the Mertonian norms for scientific integrity. These are communalism (C, collegiality and the common ownership of science and its products), universalism (U, free and open access to scientific pursuits and products) and organised scepticism (OS, exposure to critical scrutiny and possible refutation).

Matters identified in the practice of science apply throughout the renewal of theory of evolution by natural selection and point to the proposed ontology as an important opportunity for addressing current and future challenges in One Health. A guiding premise is that science is served by laws and theories as separate but mutually supporting concepts. A law in science is a ‘descriptive generalization about some aspect of the natural world’ (National Academy of Sciences, 1998) and is exemplified by the laws of thermodynamics and motion in the physical sciences. Theories are ‘comprehensive explanations of aspects of nature that are supported by vast bodies of evidence such that they can be used to make predictions about natural events or phenomena that have not yet been observed (National Academy of Sciences, 2009). Theories maintain and enhance their usefulness by being revised and expanded in detail in the light of new knowledge (Mayer and Gamble, 2024).

Evolution theory (the theory of evolution by natural selection) teams with cell theory and germ theory as one of only three defensible scientific theories that operate in biology and form its foundations. The history of germ theory demonstrates how semantic and terminological confusion, ambiguities and vagueness can impede the progressive enhancement and practical utility of theories. The same issue has also affected evolution theory and these problems and their impacts have been examined according to the passage of time. Confusion around the meaning of theory in science and theory in the sense of a conjecture or speculation came to to light as a critical defect that demands remedy. In this regard, the definition of theory from the National Academy of Sciences (2008) dubbed Theory A (Science) can be seen as an historical turning point that justifies a renewal of evolution theory. An ontology constitutes an ingenious and self-evident method for renewing evolution theory in an intelligible, accessible and practically useful form with regard to One Health.

Universally intelligible and accessible exchange of information and knowledge drives One Health and requires systems of communication unimpeded by language barriers. International bodies like the WHO, the FAO, the WOAH, the OECD and the World Bank address this matter by having multiple official languages that include English, French, Spanish, Arabic, Chinese and Russian. FAO has the Agricultural Information Management System (AIMS, https://aims.fao.org)and AGROVOC, a multilingual controlled vocabulary (https://www.fao.org/agrovoc/home), that seeks to improve access to knowledge and assist global food production. Factors affecting language barriers and information management include the primary vehicular or bridge language for science and hazards to clarity such as semantic and terminological confusion and misconceived concept hierarchies. Linguistic diversity in science is being pursued as part of the open science initiative and has been given impetus by the Helsinki Initiative on Multilingualism in Scholarly Communication

(2019) with support from UNESCO (2022) and the Council of the European Union (2022). The key issue is that any vehicular language must be purged of vernacular hindrances to enable effective communication between people with different native languages.

Misinformation, disinformation, untruths, quackery (pretence of knowledge and skills) and so-called junk science have been a perennial hazard for One Health. Their potential for harm is said to have reached 'crisis proportions' (West and Bergstrom, 2021) and this is important background for the proposed user interface between the theory of evolution by natural selection and One Health. West and Bergstrom (2021) report that misinformation threatens international peace, democratic decision-making, public health and the well-being of the planet. Misinformation has undermined control and management of COVID-19 pandemic and has prompted the World Health Organization's declaration of an 'infodemic' (Zaracostas, 2020). Misinformation in evolutionary biology has fuelled by social movements such as eugenics and social Darwinism and by the naturalistic fallacy which has been employed to rationalise malign human behaviour and immorality. ' In *The Descent of Man and Selection in Relation to Sex* (1874), Darwin rules out the naturalistic fallacy by stating that 'any animal whatever, endowed with well-marked social instincts, the parental and filial affections being here included, would inevitably acquire a moral sense or conscience, as soon as its intellectual powers had become as well, or as nearly as well developed, as in man.'

Practice in One Health and its use of evolutionary biology is helped by a perspective on the translation and extension of knowledge and skills. There are many descriptions of the notion of translation as it applies to medicine and the notion of of extension as it applies to agriculture. The gist of both is captured in an aphorism from Johann Goethe (1749-1832): 'Knowing is not enough; we must apply. Willing is not enough; we must do'. In public health, translation aims at implementing sound processes for disease treatment and prevention and the promotion of good health. In agriculture, extension aims at putting knowledge into practice, thereby benefiting society as a whole. Put simply, translation and extension are processes for putting knowledge to definite effect. Both notions are empowered by the sharing of knowledge and the mutual recognition of skill, and both attest to the ideals of education and knowledge societies (UNESCO, 2005). The observations, experience and tacit knowledge of animal carers, agriculturalists and others open the way to new explicit knowledge according to what Ritchie-Calder (2007) describes as a synergism between the know-how of technology and the know-why of academic science.

Part two of the three-part renewal process is set out in Chapter 3 and provides a perspective from history with crucial implications on how evolutionary biology can be fitted to the purposes of One Health. History in the sense of 'how things came to be' has an indispensable role in diagnosis across One Health where it informs about the primary and secondary causative factors that harm the health and well-being of individuals, populations, communities, ecosystems and the planet. Diagnosis of the historical encumbrances to the intelligibility of evolutionary biology was assisted by analysing where and how salient polysemous and troublesome words were used in various documents that came after publication of *Origin of Species* and whether this usage indicated an

appreciation of the nature of laws, theories and hypotheses in the practice of science. The words theory and nature (noun) plus natural (adjective) were the primary concern in this case study and were complemented with 34 other words that have affected past expositions of evolution theory. The process of textual scanning informed some of the precising definitions of concepts required for rigour within the proposed ontology.

Three senses of the word ‘theory’ applied to the diction analysis. Theory A (Science) refers to the sense of a ‘scientific principle to explain phenomena’ and is consistent with the word as it applies within science (National Academy of Sciences, 1998 and 1999; National Research Council, 2008). The words ‘doctrine’ and ‘dogma’ are decidedly not synonyms for Theory A (Science). Theory B (Idea) merges the senses of ‘speculation’, ‘idea formed by speculation’ and ‘hypothetical circumstances’ and dates to at least 1828. Theory C (Principles) refers to the sense of the ‘rules and techniques applying to a particular subject’ as in music theory. Nature A (Essence) refers to the senses of the intrinsic character of a person or thing or the real appearance or aspect of a person or thing and this usage dates to at least 1828. Nature B (Forces) has the sense of the ‘forces controlling the living world’ and this usage dates to at least 1828. Nature C (Physical World) has the sense of the physical world including all natural phenomena and living things. This usage also dates to at least 1828. Darwin used the word theory only in the sense of Theory A (Science) throughout *Origin of Species*.

Nature B (Forces) functions in Darwin’s view of natural selection within *Origin of Species* and frames the scientific knowledge available at the time. Page 63 of *Origin of Species* reflects Nature B (Forces) when it states that: ‘So again it is difficult to avoid personifying the word Nature; but I mean by Nature, only the aggregate action and product of many natural laws, and by laws the sequence of events as ascertained by us’. Forces are implied within the phrase ‘aggregate action and product of many natural laws’ and this leads to wider notions of causality and causation. In consequence, forces as agents of change can be aligned with present day scientific knowledge where evolution is a phenomenon and natural selection provides its causal processes. Nature as Nature A (Essence) explains the causal processes or ‘forces’ of evolution and supersedes Nature B (Forces) in structuring the ordered sequence of concepts that make up proposed ontology and shape the definition of natural selection. The precising definition of natural selection designed for the proposed ontology centres on the consequences of interactions between the nature or essential properties of life forms (Nature A, Essence) and the nature or essential properties of the environment (Nature A, Essence).

A sample of books from the field of biology that demonstrate different perspectives on evolution theory were used in a case study that explored the incidence and usage of two sets of words. The first set of words for the case study comprised theory, nature and natural and were accompanied by doctrine, hypothesis, dogma and thesis and the suffix -ism which overlap with some senses of the word theory and are completely incompatible with Theory A (Science). The search for theory in the case study demonstrates progress towards a proper understanding and correct use of the word. Theory A (Science) was absent from the works of Spencer (1887 and 1889) Fisher (1930) Haldane

(1932) and Huxley (1942). This unexpected finding renders these highly influential works defective and inapplicable to present day needs. Progress has been made and Theory A (Science) has clear-cut use in textbooks on evolutionary biology published since 2020. This final observation establishes an ontology for evolution theory based on Theory A (Science) as a rational and timely development that can remedy past misconceptions and impediments to understanding. The search for ‘nature’ and ‘natural’ led to the use of Nature A (Essence) in the definition of natural selection designed for the proposed ontology and described above. This sense of ‘nature’ centres on the consequences of interactions between the nature or essential properties of life forms and the nature or essential properties of the environment. Nature A (Essence) is defined as the 'essential qualities or properties of a thing: the inherent and inseparable combination of properties essentially pertaining to a thing and giving it its fundamental characters’.

The second set of words explored in the case study comprised several groupings. Fit, fitness, adapt and adaptation grouped together because they have been obscured in meaning and come under discussion at various times according to catchwords of ‘adaptation-ism’ and ‘selection-ism’. Precising definitions were constructed for fitness, selection and adaptation and remove the historical diversions of ‘adaptationism’ and ‘selectionism’.

Other groupings in the second set of words for the case study include environment, viable, viability and metabolism. These words and their underlying concepts were unavailable to Darwin and could have replaced his necessity to use of figurative and allusive language in *Origin of Species*. Darwin’s phrase, the ‘conditions of life’, encompassed the current ecological meaning of environment and the workings of life forms. Viability is the crux of definitions for fitness and is depicted as follows: *Viability for organisms is the capability for life, being alive and living and for biological entities such as viruses and prions is the capability for existing and executing life cycles based on propagation within organisms and transmission among organisms*. Darwin’s allusions to the ‘struggle for life’ and ‘struggle for existence’ could have been embellished by reference to metabolism as *the integrated network of biochemical reactions that support viability in living organisms and biological entities such as viruses and prions.*

Race was searched for in the case study because of its harmful interpretations within eugenics and social Darwinism and its meaning can conveyed by the word population as it applies in epidemiology and ecology: *A population is any complete group with at least one characteristic in common or an aggregate of things, creatures, cases and so on*. Reproduction and replication explored and given precising definitions in order to connect the ontology for theory of evolution by natural selection with the central biological concept of organisation. Examination for the words inheritance (which Darwin qualified with the phrase ‘as implied by reproduction’), variation and selection showed that these were the firm pillars for evolution in *Origin of Species* and remain so today. The ontology for evolution theory builds around inheritance as the transmission and reception of genetic information from generation to generation via the processes of reproduction and heritability as the capacity for being transmitted from one generation to the next.

Issues around the term species and their implications for the proposed ontology including their coverage of viruses and prions were also explored in Chapter 3. Zachos (2016) provided a list of 32 annotated species concepts all of which suited particular purposes in different branches of biology. The result shown below extends to biological entities such as viruses and prions[2], which clearly exhibit Darwin's 'descent with modification'. In short, species are discrete populations of life forms possessing communal properties for reproduction. The idea of species as reproductively circumscribed populations of life forms encompasses the phenomenon of genome mixing that occurs in viruses and which is prominent in the emergence of new disease causing variants.

Part three of the three-part renewal process is set out in Chapter 4 and fleshes out the opportunities from information technology that can facilitate the management of present-day biological knowledge and its advances. Chapter 4 starts with some more thoughts on software engineering and provides a precising definition for an ontology as the vehicle for renewing aspects of evolutionary biology. In essence, the term 'ontology' refines the pre-existing notion of a conceptual framework, which can be stated as a hierarchical arrangement of interrelated concepts that allows an explanation and understanding of a subject. Conceptual frameworks and ontologies align easily with Theory A (Science) as a coherent statement or set of ideas that explains observed facts or phenomena and correctly predicts new facts or phenomena not previously observed.

Conceptual frameworks and ontologies support the quality of scientific models by clearly explaining the variables employed in them and can apply to all modes of rational discourse. considering a variety of issues in the practice of science, including some more thoughts on teleology and the nature of explanations and definitions, a reiteration of the meaning of the words 'nature' and 'theory' and a proposal that the theory of evolution by natural selection, cell theory and the germ theory of disease, as the only theories in biology that fit within the denotation of Theory A (Science). Since One Health has its roots in the broad disciplines of physiology and this union of theories forms a cohesive and interdependent whole that can guide sound practice. To explain, explanations in both physiology and pathology begin with and centre upon cell theory and the interactions within and between cells, tissues, organs and whole organisms. Germ theory comes into play when infection is involved. Evolution theory can then follow and add new perspectives and insights to the primary explanations provided by cell theory and germ theory.

Chapter 4 continues with part three of the three-part renewal process by expanding on the role of definitions, explanations and reasoning in contemporary science and attending to the matter of teleology. The entire effort to renew the theory of evolution by natural selection and the definitions proposed for terms such as evolution, inheritance, selection, adaptation and species depends on the premise that the word 'definition' can have a clear and unequivocal meaning that facilitates universal intelligibility within the proposed ontology for the theory of evolution by natural selection. In this regard, a definition seeks to ascertain and encapsulate the characteristics and nature of a thing and so identify and explain what a thing is and precising definitions aim at

[2]The writings that made for the modern synthesis (Fisher, 1930; Haldane, 1932; Huxley, 1942) contain a single passing reference to a virus being a possible cause of variation in *Drosophila* spp. of fruit-fly (Huxley, 1942).

minimising ambiguity and vagueness in particular contexts. Precising definitions of key concepts and factors in evolution have been constructed to render substance of the ontology intelligible, universally accessible and open to modification in the light of new knowledge. The fact that mathematical models are compromised and can be counterproductive and sources of harm when their variables are inadequately or wrongly defined has implications for the use of mathematical models in epidemiology. According to George Box (1919-2003), ‘all models are wrong, but some are useful’.

Contemporary definitions for theories in science hinge upon the word ‘explanation’. In consequence, the present task of renewing the theory of evolution by natural selection may be assisted by a philosophical perspective on this crucial word. The deductive-nomological (DN) model for explanation states that an explanation in science is composed of an *explanandum* (the phenomenon or thing to be explained) and an *explanans* (a collection of propositions that combine to account for the *explanandum*). So, the phrase ‘origin of species’ in the title of Darwin’s book is the *explanandum* and the phrases ‘by means of natural selection, or the preservation of favoured races in the struggle for life’ refer to the *explanans*.

The deductive-nomological (DN) model for explanation is appropriate for use in One Health, because it aligns with the causal reasoning used in clinical practice and similar reasoning applies to agriculture and resource management. Causal reasoning and its alliance with hypothetico-deductive reasoning and iterative hypothesis testing are integral to the usual diagnostic processes employed in medicine and veterinary medicine. Causal reasoning is ‘an aspect of the diagnostic process based on the anatomic, physiologic and biochemical mechanisms that operate in the normal workings of the human body and the changed behaviour of these mechanisms in disease.

Causal reasoning and the deductive-nomological (DN) model of explanation can attend to issues arising from ‘teleology’ that have constricted evolutionary thought both before and after publication of the *Origin of Species*. The coupling of descent with modification to natural selection in *Origin of Species* challenged a particular teleological paradigm that development of life on earth reflected the ‘unfolding of a coherent plan aimed at a predetermined goal’. The teleology-teleonomy wrangle is historically significant but can be regarded as irrelevant to the proposed ontology for the theory of evolution by natural selection that can inform One Health. Aetiology which refers broadly to the study of causes and the assignment of causes, origins, or a reasons for something overrides teleology. Aetiology looks to ‘reasons for’ and teleology looks to ‘purpose of’.

Next comes a general survey of the properties, attributes and so on that identify and characterise life and living systems (section 4.2). Considerations extend to terms such as ‘biont’, ‘life form’ and ‘organic being’, an overview of thermodynamics and concepts of agency and information that allow for some refined definitions of life. Then follows some detailed explorations of aspects of life relevant to the proposed ontology for the theory of evolution by natural selection (section 4.3). Matters covered are organisation as basic to life, the patterned processing of energy and information that epitomises life, the concept of agency, death and its equivalent in life forms, reproduction and

inheritance as fundamental to life forms (including epigenetics, niche construction and ecosystem engineering), homeostasis and associated concepts affecting responsiveness and adaptability (including phenotypic plasticity and reaction norms), associations within and between life forms (ranging from predation to co-operative mutualism) and finally viruses and prions as life forms. Precising definitions are constructed for life itself covering both cellular organisms and sub-cellular life forms (viruses and prions) and a selection of other concepts and terms.

Last in part three of the three-part renewal process (Chapter 4) is an exploration of diagrams or schemes showing the relationship between things and ideas and their value in complementing written text and enhancing the communication of issues associated with the renewal of the theory of evolution by natural selection for application in the One Health. Note here that ontologies employed in information technology and artificial intelligence qualify as diagrams as does the ontology proposed for evolution theory, which will be instructed by an explicit generic concept hierarchy. Groundwork for organising and assembling this ontology comes from a series of diagrams that illuminate the elements of evolution theory. The series starts with a triangle that depicts the scope of biology and unifies and coordinates germ theory, cell theory and evolution theory for practice in One Health (Figure 2, section 2.2). The series continues with Figure 4 (section 4.1.1) that outlines the archetype of the fire triangle, the example of the well-known epidemiological triangle and attempts at triangles for germ theory and evolution theory. The epidemiological triangle and the triangles for germ theory and evolution theory highlight the commonality of interactions between life forms and the environment and the role of agency in producing either disease, infectious disease or evolution (Darwin's descent with modification).

The third and last part of this 'one long argument' or process to renew evolution theory for present-day use in One Health began in Chapter 4 with a commentary on opportunities from information technology (IT) for packaging biological knowledge and optimising its practical and productive application. Reliable and effective performance in information technology (IT) requires a clear-cut and unambiguous comprehension of ideas, entities, factors and variables and their relationships that can be obtained by means of precising definitions (see section 1.1.4) and the use of concept hierarchies. The same requirement applies to the present renewal of the theory of evolution by natural selection and can met by approaches used in information technology (IT), artificial intelligence and knowledge engineering. Ontologies, or 'representations of knowledge as a set of concepts and relationships that exist among those concepts' (Neapolitan and Jiang, 2018), provide the methodology and their utility can generalise across all forms of rational discourse. An ontology can rectify the adverse impacts of linguistics, diction and argumentative discourse on past expositions of theory of evolution by natural selection (see Chapter 3). Ontologies are given sense sby a clear and diagrammatic view of their determinants and components.

Darwin used the phrase 'the laws acting around us' to explain the component causes that bring about evolution in life forms. The word 'laws' is supplemented by the word 'factors' to highlight the present day meaning of laws in science as concise statements that describe consistent, observable relationship in nature. These 'laws' or 'factors' are explained according to current biological

knowledge and with an emphasis on physiology. Renewal of the substance of evolution theory was expedited by Figure 9 which sets out the structure of the proposed ontology in line with a concept hierarchy and points to the precising definitions for its component parts. These enlighten ‘the laws [factors] acting’ in life forms and also in the environment. Figure 9 frames some further reflections and is a resource for finalising the ontology for evolution theory in Chapter 6. Evolution theory embellishes the perspectives, insights and foresight provided by cell theory and germ theory. The whole of biology includes One Health and the practical wisdom, ‘phronesis’, that drives its application (Abassi, 2011). Atomic theory does the same thing as this trio of theories and integrates the whole of chemistry.

A final word of paramount importance is that Figure 9 displays a precising definition for species, which can expedite an understanding of the mutation rates in viruses that drive their evolution and lead to the continuing epidemic and pandemic viral diseases that confront One Health and provide abundant cause for the renewal of evolution theory. Species are depicted as discrete populations of life forms that possess communal properties for reproduction. Mutation rates in viruses vary according to the nature of informational macromolecules and mutation rates in single-stranded RNA viruses such as the influenza, MERS, SARS CoV-1 and SARS CoV-2 viruses can be prodigious. The consequence is continual emergence of new forms of epidemic and pandemic diseases. Two sources of mutation are in play. One is the absence of proof-reading mechanisms in single-stranded RNA viruses that govern genome replication. The other is genome mixing which requires hosts that can be infected simultaneous with two or more variants of the same viral species and interactions between multiple host species. Some hosts may be non-permissive to some of these variants but can become permissive to new variants when mixing vessels hosts are present. Mixing vessel hosts are permissive to concurrent infections with multiple variants of a viral species and allow for the genome mixing that generates new viral subpopulations with new capabilities including extended host ranges, virulence, modes of transmission and persistence in the environment.

Darwin’s example is followed and matters inspiring, guiding and shaping the present renewal are then ‘briefly recapitulated’ as part 4 in Chapter 5 before assembling the ontology or type of conceptual framework for theory of evolution by natural selection from its explicitly defined component parts (part 5, Chapter 6). Recapitulation in Chapter 5 covers matters raised under the headings of setting the scene (Chapter 2), the historical context for a renewed version of the theory of evolution by natural selection (Chapter 3) and pathways to renewed version of the theory of evolution by natural selection (Chapter 4). Recapitulation of these various interrelated matters in Chapter 5 is preceded by some thoughts about the word ‘renew’ which shapes the present effort.

Part 5 (Chapter 6) is the climax of the report where the ontology proposed to expedite the utility of evolutionary biology in One Health is assembled along with the accompanying precising definitions for terms and concepts. The ontology for evolution theory is founded on the premise that evolution theory, cell theory and germ theory act as harmonised and interdependent trio that can enlighten the practice of One Health. Cell theory acts as the super-ordinate theory within this trio because it frames the attributes, properties, elements, conceptions and characteristics that identify life, living

entities and viability. The climax foreshadows an application of the ontology in marshalling the concepts and factors that lead to the emergence and re-emergence of infectious diseases and presenting them as concise and comprehensive formula, recipe or protocol assisted by an adaptation of the truth table used in logic and information technology. This ontology is relevant to the WHO pandemic agreement that was ratified on 20th May 2025 and to the aims of FAO's AIMS and AGROVOC initiatives to overcome language barriers in the equitable sharing of scientific knowledge.

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CAC: Codex Alimentarius Commission (CAC) is an intergovernmental body, established by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), that develops international food standards, guidelines, and codes of practice.
CDC: The Centers for Disease Control and Prevention (CDC) is the national public health agency of the United States.
EC: The European Commission (EC) is the primary executive arm of the European Union (EU).
EFSA: The European Food Safety Authority (EFSA) is a European Union agency that provides independent scientific advice and support on food and feed safety, as well as other related areas like plant health and animal welfare.
EU: The European Union (EU) is a supranational political and economic union of 27 member states that are located primarily in Europe.
FAO: The Food and Agriculture Organization of the United Nations (FAO) is a specialized agency of the United Nations that leads international efforts to defeat hunger and improve nutrition and food security.
IPCC: The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.
NAS: The National Academy of Sciences of the USA (NAS) is a private, non-profit organization that recognizes and promotes outstanding science. It was established in 1863 and provides objective, science-based advice to the nation. The NAS includes the National Academies of Sciences, Engineering, and Medicine, and membership is considered a high honor for scientists.
OECD: The Organisation for Economic Co-operation and Development (OECD) is an intergovernmental organization with 38 member countries that was founded in 1961 to stimulate economic progress and world trade.
OHHLEP: The One Health High-Level Expert Panel is the scientific and strategic advisory group to the Quadripartite organizations - the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), the World Health Organization (WHO) and the World Organisation for Animal Health (WOAH) – in their collaboration on One Health.
OH JPA: The One Health Joint Plan of Action (OH JPA) of the WHO is designed to create sustainable and holistic solutions to better manage threats to the health of humans, animals, plants, and the environment and prevent potential future pandemics.
OIE: The global authority on animal health that was founded in 1924 as the Office International des Epizooties (OIE) since May 2003 known as the World Organisation for Animal Health (WOAH).
PRET: The Preparedness and Resilience for Emerging Threats (PRET) initiative is an innovative approach to improving disease pandemic preparedness. It recognizes that the same systems, capacities, knowledge, and tools can be leveraged and applied for groups of pathogens based on their mode of transmission (respiratory, vector-borne, foodborne etc.). It places the principles of equity, inclusivity, and coherence at the forefront. PRET provides a platform for national, regional and global stakeholders to collaborate to strengthen preparedness.

SDGs: The 17 world Sustainable Development Goals (SDGs) were adopted by all members of the UN in 2015 and have the aim of "peace and prosperity for people and the planet", while tackling climate change and working to preserve oceans and forests. The SDGs highlight the connections between the environmental, social and economic aspects of sustainable development. Sustainability is at the center of the SDGs, as the term *sustainable development* implies.

UK: The United Kingdom of Great Britain (England, Scotland and Wales) and Northern Ireland.

UN: The United Nations is an international organization founded in 1945. Currently made up of 193 Member States, the UN and its work are guided by the purposes and principles contained in its founding Charter. The UN has evolved over the years to keep pace with a rapidly changing world and remains the one place on Earth where all the world's nations can gather together, discuss common problems, and find shared solutions that benefit all of humanity.

UNEP: The United Nations Environment Programme (UNEP) is the leading global authority on the environment with a mission to inspire, inform, and enable nations and peoples to improve their quality of life without compromising that of future generations. UNEP works with governments, civil society, the private sector and UN entities to address humanity's most pressing environmental challenges - from restoring the ozone layer to protecting the world's seas and promoting a green, inclusive economy. UNEP is driving transformational change by drilling down on the root causes of the triple planetary crisis: the crisis of climate change, the crisis of nature, land and biodiversity loss, and the crisis of pollution and waste.

UNESCO: The United Nations Educational, Scientific and Cultural Organization (UNESCO) is a specialized agency of the United Nations with the aim of promoting world peace and security through international cooperation in education, arts, sciences and culture.

USA: The United States of America.

WHO: The World Health Organization (WHO) is a specialized agency of the United Nations which coordinates responses to international public health issues and emergencies. It is headquartered in Geneva, Switzerland and has six regional offices.

WOAH: The World Organisation for Animal Health (WOAH) is global authority on animal health. It was Founded in 1924 as the Office International des Epizooties (OIE) and in May 2003 adopted the common name World Organisation for Animal Health. WOAH is an intergovernmental organisation that focusses on transparently disseminating information on animal diseases, improving animal health globally and thus building a safer, healthier and more sustainable world.

WTO: The World Trade Organization (WTO) is the only international organization dealing with the rules of trade between nations. At its heart are the WTO agreements, negotiated and signed by the bulk of the world's trading nations and ratified in their parliaments. The fundamental goal of the WTO, as set out in the organization's founding agreement, is to use trade as a means to improve people's living standards, create better jobs and promote sustainable development.

Chapter 1. Introduction and Methods

'A theory is a good theory if it satisfies two requirements. It must accurately describe a large class of observations on the basis of a model that contains a few arbitrary elements, and it must make definite predictions about the results of future observations': Stephen Hawking (1988) *A Brief History of Time: From the Big Bang to Black Holes*.

1. Introduction

The theory of evolution by natural selection[3] whose inception can be traced to Charles Robert Darwin (b. 1809, d. 1882) and Alfred Wallace Russell (b. 1823, d. 1913) in their books 'The Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life' (Darwin; five editions from 1859 to 1876 – *Origin of Species*) and 'Darwinism: An Exposition of the Theory of Natural Selection with Some of its Applications' (Wallace, 1889 - *Darwinism*) bears upon all aspects of biology and has provided important insights into the spectrum of health, ill-health and disease in animals, people and all living systems (Gluckman et al., 2011; LeGrand and Brown, 2002; Omenn, 2010; Nesse and Stearns, 2008). In consequence, evolutionary biology has been advanced as a 'basic scientific discipline' for medicine (Grunspan et al., 2018 and 2019; Nesse et al., 2010) and specialised textbooks provide entry to the subject matter (Gluckman et al., 2017; Perlman, 2013). A somewhat similar proposal on the value of evolutionary biology is now explored for One Health-Global Health-Planetary Health and its component parts, which extend to veterinary medicine, agriculture and natural resources management. One Health embraces biosecurity and refers to the safeguarding against biotic or biological sources of harms (Mackenzie and Jeggo, 2019). Sources of harm include epidemic diseases and this undertaking culminates with a proposal for how evolution theory can merge with germ theory and thus enlighten One Health responses to these persistent hazards as outlined in WHO's proposed pandemic agreement (WHO, 2024).

1.1 Issues and considerations

1.1.1 Past impediments to articulating theory of evolution by natural selection and present opportunities for progress

Present opportunities for progress and past impediments to progress are foremost considerations for this task around evolutionary biology. Opportunities arising from practice in information technology and artificial intelligence can renew theory of evolution by natural selection in an intelligible, disciplined and actionable form that meets current needs and challenges. Impediments relate to communication and linguistics and demonstrable failures to appreciate the nature of scientific laws, principles, theories and hypotheses. Figurative language, polysemy (the use of words with with many possible meanings) and argumentative or promotional discourse[4] that overshadowed the coherent exposition of facts, concepts and reasoning have all had an adverse impact on the

[3]The designation 'theory of evolution by natural selection' appears to have been pioneered by Romanes in his book, *The Scientific Evidences Of Organic Evolution* (1882).

soundness and presentation of knowledge in evolutionary biology and on the mode and fidelity of its universal communication. The situation has been compounded by misanthropic issues such as social Darwinism that resonate from the history of evolutionary biology. Vestiges of social Darwinism and its misguided ideology persist into the 21st Century (Contera, 2021; Kendi, 2019) and may do harm to social cohesion as an unwarranted by-product of so-called meritocracy (Guinier, 2016; Littler, 2018; Markovits, 2019; McNamee and Miller, 2014; Sandel, 2020). These vestiges may also compound detrimentally with climate change denialism (Berg, 2016; Rees, 2013; Stern et al., 2016; Thorp, 2020), unsustainable land-use practices (Ellis, 2019; Paul et al., 2020; Pretty, 2018), failure to recognise that economies rely on the flow of goods and services generated in the natural world (Johnson et al., 2021) and the wilful misinformation that has hampered public health responses to the COVID-19 pandemic (WHO, 2021). For convenience, the customary name, "Theory of Evolution by Natural Selection", will be abbreviated to "evolution theory" within this document

1.1.2 The nature of One Health

As to One Health[5], the American Veterinary Medical Association states that 'humans, animals, and the world we live in are inextricably linked' and that One Health is the 'collaborative effort of multiple disciplines working locally, nationally, and globally to attain optimal health for people, animals, and the environment' (AVMA, 2008). One Health epitomises 'the integrated view that humans exist as part of nature' (Falvey, 2020)[6] and that human lives and health are interwoven with the health of the environment and the animals that inhabit it (FAO, 2013a; Mubareka et al, 2022).

This consolidated view transforms One Health to global or planetary health or the health of people, places and planet (FAO, 2013a; Butler, Dixon and Capon, 2015; Rabinowitz et al., 2018; Walton, 2019) and ambitions for a biosensitive society[7] (Boyden, 2016). In doing so, it affirms the importance of environmental resources management and its expression within responsible agriculture (FAO, 2011). Food security and sustainable agriculture depend absolutely on the world's life support systems and can be enhanced by attention to ecosystem services (FAO, 2011, Tamburini et al., 2020). In consequence, the Health/Global Health became the subject of quadripartite action

[4]See Vivian and Jackson (1961) *English Composition*. Barnes and Noble Inc., New York and Glossary. Exposition as a form of discourse aims to explain, inform, or describe a subject, presenting facts, definitions, or explanations to enhance the audience's understanding. Argument as a form of discourse seeks to persuade or convince the audience by presenting claims supported by evidence and reasoning, aiming to influence beliefs or actions.

[5]Capitals are used for One Health throughout this review. By convention, capitals are applied when words describe the names of institutions, organisations, departments, bureaus, courts and companies or brand names, trademarks, logotypes and the like to assign proprietorial rights (Emerson, 1987; Peters, 1995). One Health is proposed as an institution which provides an open, inclusive and universal forum, based upon the tenets of science, where people with different skills and experience can cooperate and collaborate for the common good. One Health is not a separate discipline or speciality that requires esoteric qualifications. Common or universal ownership, stewardship and shared responsibility applies to One Health.

[6]A similar view operates in the Universal Declaration on Bioethics and Human Rights (UNESCO, 2005). Article 17 (Protection of the environment, biosphere and biodiversity) states: *Due regard is to be given to the interconnection between human beings and other forms of life, to the importance of appropriate access and utilization of biological and genetic resources, to respect for traditional knowledge and to the role of human beings in the protection of the environment, the biosphere and biodiversity.*

[7]A biosensitive society is a society that is based on an understanding the human place in nature and in which human society is sensitive to, in tune with, and respectful of the processes of life (Boyden, 2016).

from the Food and Agriculture Organisation of the United Nations (FAO), the United Nations Environment Program (UNEP), the World Organisation for Animal Health (WOAH) and the World Health Organisation (WHO)[8](see OIE, 2017). Ultimately, One Health/Global Health builds upon WHO's broad definition of human health (WHO, 1946), which covers physical, mental and social well-being, and the general notion of public health, which is 'the organised response by society to protect and promote health, and to prevent illness, injury and disability' (McIntyre, 2011).

An updated definition of One Health (OHHLEP, 2022) is set out in Appendix 1. This represents a landmark in the history of One Health and encompasses what has been called Global Health and Planetary Health. It synthesises and amalgamates past and present knowledge and inspires the strategic vision in the quadripartite One Health Joint Plan of Action (2022–2026)*(*FAO, UNEP, WHO, and WOAH; 2022), which grew from the earlier tripartite agreement. This Plan of Action is aimed at comprehensive and inclusive action to address human, animal and ecosystem health. In doing so, it necessarily and inevitably embraces the protection of biodiversity, climate change mitigation, amelioration of social inequalities, clean air and energy and food and water security. Ghai et al (2022) discuss the framework of One Health and how it relates to the control of zoonoses and meshes with other hazards such as climate change and how resources can be mobilised to meet needs. The term One Health embraces concepts of Planetary Health and Global Health throughout this monograph.

The One Health Joint Plan of Action is bound to the idea of sustainability as it applies to food systems and described by the FAO (https://www.fao.org/3/ca2079en/CA2079EN.pdf) and the US Department of Agriculture (https://www.usda.gov/oce/sustainability/definitions). To quote the FAO: A sustainable food system (SFS) is a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised. This means that: (1) It is profitable throughout (economic sustainability); (2) It has broad-based benefits for society (social sustainability); and (3) It has a positive or neutral impact on the natural environment (environmental sustainability). Sustainability is governed by the laws of thermodynamics and this reality guides agroecology (for example: Altieri and Nicholls, 2005; Gliessman, 2007) and regenerative farming (for example: Massy, 2020).

1.1.3 Contemporary challenges in One Health

Evolutionary thinking has already contributed to the knowledge base for veterinary medicine and One Health by providing helpful perspectives on host-pathogen and host-parasite interactions (Sprent, 1962; Ewald, 1994; Frank, 2002), mechanisms operating in the immune response (Cohn et al, 2007), and resistance to antimicrobials (Baquero et al., 2015; McEwen and Collignon, 2018; Collignon and McEwen, 2019), anthelmintics (Waller, 1997) and pesticides (Georghiou, 1972).

[8]The WHO definition of One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes that the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent. (https://www.who.int/health-topics/one-health#tab=tab_1, 2023).

These instances reflect the use of evolutionary thinking to meet specific needs. In doing so, they raise the prospect that veterinary medicine and One Health may benefit from an evolutionary perspective that is applied more deliberately and systematically and in a way that bolsters all other disciplines in biology and and harmonises proximate and ultimate causation. To explain, proximate causation refers to how cellular organisms [and sub-cellular life forms such as viruses and prions] respond to their immediate environment, through behaviour, physiology and other means, and ultimate causation refers to the evolutionary factors behind these responses and the utility of these responses within a biological system (Rittner and McCabe, 2004). Relationships between so-called functional biology with an emphasis on proximate causation and evolutionary biology with an emphasis on ultimate causation (Mayr, 1961) and are topics for continuing discussion (Thierry, 2005; Laland et al., 2011; Noble et al., 2014); Corning, 2019). However, both are accounted for and operate in the causal models applying throughout One Health and both are covered by the long-established concept of aetiology.

Two particular concerns plus the realities of transboundary animal diseases and pandemics, amply demonstrated by foot and mouth disease, avian influenza, African swine fever and COVID-19, warrant a comprehensive and detailed compilation of arguments around the utility of evolutionary biology for One Health. One particular concern is the promotion of optimum interoperability, or the capability for reciprocal function, within the world's veterinary services (see OIE, 2015 – now WOAH, World Organization for Animal Health). Another particular concern comes from FAO's call for a 'paradigm shift in risk assessment' in order to track the drivers of disease emergence, spread and persistence and to design countermeasures (FAO, 2013a). These drivers can be arrayed according to interactions among pathogen populations, host populations and the environment, including the reality of climate change (Zinsstag et al., 2018; Özkan et al., 2022), land use and misuse, international trade and other elements in the general human-animal-ecosystem interface (FAO, 2013).

1.1.4 Aims and objectives of the present endeavour

So, the broad objective of the present endeavour is to create a modifiable repository, inventory, portfolio or catalogue of data, information, knowledge and ideas that can inform further and more specific reflections upon how evolutionary biology may enhance One Health. The theme is a reformulation of Darwin's 'one long argument', a phrase he used in the final Chapter of *Origin of Species* (1872) to describe the substance of 'descent with modification through variation and natural selection'[9]. The final product could help towards the 'paradigm shift in risk assessment' (FAO, 2013a) and the explicit use of systematic reviews (Institute of Medicine, 2011) to characterise hazards or sources of harm (CAC, 2015). The present endeavour also doubles as an extensive update of the fundamentals that guide biology and a resource for lifelong learning. An overriding fundamental is that life at all levels and in all forms concerns exchanges of matter and energy and is

[9] 'As this whole volume is *one long argument*, it may be convenient to the reader to have the leading facts and inferences briefly recapitulated': quotation from Chapter XV, Recapitulation and Conclusion in The Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life (Darwin, 1876).

governed absolutely by the laws of thermodynamics (Schneider and Sagan, 2005; Schrödinger, 1944; Wicken, 1998).

The breadth of coverage, the extent of detail (including an abundance of footnotes) and the need to address controversies within the history of evolutionary biology foreclose upon the usual routes for publication. However, the effort provides ingredients and supporting material, in the form of words and supporting diagrams, for further and more succinct publications. It also sets the scene for critical feedback according to the organised scepticism that empowers science (Merton, 1942) and subsequent 'descent with modification', which was Darwin's phrase for evolution. An immediately achievable objective aligns with aspirations for an open science and the need to address language barriers (WHO, 2020a; UNESCO, 2021). This immediate objective is to craft a universally accessible and reliable user-interface for the practical application of natural selection theory within One Health and its delivery within the innovative, inclusive and coherent platform provided by two recent developments. First is the Preparedness and Resilience for Emerging Threats (PRET) initiative of the World Health Organization (WHO 2023, https://www.who.int/initiatives/preparedness-and-resilience-for-emerging-threats) and its associated national, regional and global stakeholders. Second is the quadripartite One Health Joint Plan of Action (2022–2026)*(*FAO, UNEP, WHO, and WOAH; 2022).

The user-interface in mind for evolution will take the form of a modified conceptual framework known as an ontology and constructed with methods employed in information technology (IT) and its sub-disciplines of artificial intelligence and knowledge engineering. Ontologies in information technology (IT) are required to be stringently and diagrammatically structured with specifically defined language in order to create interoperability or the ability to exchange and use information for reasoning and decision-making. The ontology in mind will be structured according to a concept hierarchy with the phenomenon of evolution or Darwin's 'descent with modification' as the superordinate concept. Precising definitions will be used to make the substance of the ontology intelligible, universally accessible and open to modification in the light of new knowledge and . Precising definitions derive from dictionary definitions and are used to minimise ambiguity and vagueness in particular contexts (Hurley, 2003). They differ from stipulating definitions, which assign a meaning to a word for the first time, and lexical definitions, which report on the meaning that a word already has in a language. Precising definitions can forestall perplexities associated with jargon and those employed in the proposed ontology are marshalled in the Glossary. The glossary is extensive and goes beyond a listing of terms with precising definitions and aims at explicating all factors and concepts alluded to in this document.

Ontologies and their necessary discipline around concepts and their interrelationships provide a means for remedying some historical encumbrances to the cogency and intelligibility of natural selection theory and evolutionary biology. The efficacy of natural selection theory in One Health depends upon strict attention to the explicit nature of laws, theories, principles and hypotheses in the practice of science (Futuyma and Kirkpatrick, 2017; National Academy of Sciences, 1999; National Research Council, 2008).

1.2. Methods and Approach

1.2.1 Systematic reviews

The general method for a systematic review applies to the present task. A review qualifies as systematic 'if it is based on a clearly formulated question, identifies relevant studies, appraises their quality and summarizes the evidence by use of explicit methodology' (Khan, 2003). A systematic review allows for scrutiny of arguments, encourages reasoned refutation, and facilitates the progressive refinement of knowledge. Systematic reviews are said to address confusion, highlight deficiencies in evidence and yield new insights by combining findings from different studies (Sense about Science, 2009) and the PRISMA statement of 2000 (Preferred Reporting Items for Systematic reviews and Meta-Analyses, https://www.prisma-statement.org/) provides broad guidance.

Systematic reviews are underpinned by literature reviews, which identify, marshal and collate information on matters in question. A literature review provides context for the arguments set out in this working paper. Resources used to identify and then access relevant publications from literature of the past were Trove (a search engine of the National Library of Australia, https://trove.nla.gov.au), Project Gutenberg, the Internet Archive (https://archive.org), the Open Library (https://openlibrary.org), Darwin Online (http://darwin-online.org.uk), the Biodiversity Heritage Library (https://www.biodiversityheritagelibrary.org) and Wikipedia https://wikipedia.org). Resources used to explore the current body of scientific literature were open access only and included PubMed from the National Library of Medicine in the US National Institutes for Health (https://pubmed.ncbi.nlm.gov), PubAg from the US Department of Agriculture National Agriculture Library (https://search.nal.usda.gov/discovery/), Google Scholar (https://scholar.google.com) and Semantic Scholar (https://www.semanticscholar.org).

1.2.2 Access to knowledge

General search engines such as Google (https://www.google.com) and Bing (https://www.bing.com) were interrogated to provide links to relevant information from national and international agencies such as WHO (World Health Organization of the United Nations), FAO (Food and Agriculture Organization of the United Nations), WOAH (World Organisation for Animal Health), UNESCO (United Nations Educational, Scientific and Cultural Organization), OECD (The Organisation for Economic Co-operation and Development), the World Bank, and so on. This represents the so-called grey literature, or literature published outside of commercial or academic channels. The grey literature has a capacity to moderate issues of quality arising from the current state of scientific publishing (Horton, 2016; Vineis, 2024).

1.2.3 Linguistic issues and universal intelligibility

Polysemous and semantically confused words such as ‘theory’, ‘nature’ and ‘natural’ and words used figuratively as in ‘struggle for life’, ‘competition’, ‘trade-off’, ‘arms race’ and ‘selfish gene’ have had problematic usage during the history of evolutionary biology and are a crucial consideration for the present enterprise, where universal intelligibility requires rigour in the definition of concepts. These words were analysed for frequency and meaning in selected documents by a process of textual scanning enabled by the search function in two pdf readers (Foxit, https://www.foxit.com; and, Master PDF Reader, https://code-industry.net). The resulting perspective from history provides for a shared present-day understanding of evolutionary biology and one that addresses language barriers and optimises interoperability within One Health (WHO, 2020a; UNESCO, 2021). The glossary within this document has language barriers and interoperability in mind and attempts to enhance the glossaries present in many common reference works. A task for the future is the development of processes for optimising accuracy and comprehension when definitions, concepts and the proposed ontology are translated from one language to another.

Another matter affecting universal intelligibility concerns shortcoming in the literature on evolution during the twentieth century as reported by Mayr (2002) and which still have an impact in general discourse. Mayr (p. xiv) commented that the volumes concerned are ‘rather poorly organized and fail to present a concise reader-friendly account [of evolution]’, do not communicate evolution as ‘answers to a series of questions’, ‘devote too much space to specialized aspects of evolution such as the genetic basis of evolution and the role of sex ratios’, ‘are too technical and use too much jargon’, overdo the principles of genetics, waste space by ‘arguing for and against obsolete claims such as the gene is the object of selection’, and fail to ‘give adequate space to an analysis of different kinds of natural selection, particularly selection for reproductive success’.

Mayr goes on to say that ‘most existing volumes on evolution have two other weaknesses’. First is failure to identify how evolutionary phenomena are shaped by major processes related to the ‘acquisition and maintenance of adaptedness and the origin and role of organic diversity’. Second is that ‘most treatments of evolution are written in a reductionist manner in which all evolutionary phenomena are reduced to the level of the gene’. Mayr states that: ‘Evolution deals with phenotypes of individuals, with populations, with species: it is not “a change in gene frequencies “. The two most important units in evolution are the individual, the principal object of selection, and the population, the stage of diversifying evolution’.

A root cause of the shortcomings Mayr identified in the literature on evolution is the lack of foundations in physiology and the absence of an understanding that organisation a key property of life forms and is based on cell theory. Mayr, however, is off track when he states that evolution is the most important concept in biology. Evolution cannot operate without a basis in organisation and cell theory. The proposed ontology for evolution theory with its accompanying precising definitions

and disciplined by its purpose of informing practice in One Health has qualities that can foreclose on the shortcomings described by Mayr.

Chapter 2. Setting the Scene for a One Health Renewal of the Evolution Theory

What comes first in this reformulation of Darwin's 'one long argument' or three-part process to renew natural selection theory and evolutionary biology according to present-day knowledge and circumstances are some thoughts on the relationship between evolutionary biology and One Health and a glimpse of how evolutionary biology can be a valuable tool across the broad scope of One Health. Key concerns are the specific nature of scientific theories and the need for a simple, concise and inclusive account of the theory of evolution by natural selection (evolution theory) that considers issues of conceptual clarity, linguistic barriers and universal accessibility to knowledge (UNESCO, 2005). The intention is to meet this particular need with a type of conceptual framework[10], an ontology[11], for the theory of evolution by natural selection that is (1) guided by methods employed in information and computer technology, software engineering and artificial intelligence[12] (Russell and Norvig, 2010; Neapolitan and Jiang, 2018) and (2) built around the explicit and distinctive meaning of the word 'theory' as it applies within science (National Academy of Sciences, 1998 and 1999; National Research Council, 2008).

Focus on the particular meaning of the word 'theory' as it applies to science and purposeful use of the term 'ontology' are both directed at a sound, comprehensive and intelligible foundation for the user-interface between natural selection theory and One Health. The terms 'ontology', 'conceptual framework' and 'model' are reviewed and elaborated in Appendix 3, which explores a range of related ideas either in everyday use or within the speciality of computer science. A conceptual framework provides a coherent platform for the application of causal reasoning (Kassirer et al., 2010) to diagnostic processes[13]. Conceptual frameworks serve as tools for exploration and reasoning within a topic area and scientific models are directed at exploration and demonstration within a topic area. Conceptual frameworks and scientific models complement one another to the benefit of both. Conceptual frameworks can identify and characterise the variables used in mathematical models. Ontologies are a specific sort of conceptual framework employed in information technology to create interoperability between systems. They must be stringently structured (for example, by means of concept hierarchies) and require explicit language and precising definitions in order to facilitate the accurate exchange and use of information.

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[10]Conceptual framework: A grouping or assemblage of concepts that are appropriately defined and systematically organised to provide a focus, rationale, and instrument for the integration, interpretation and application of knowledge and a pathway towards new knowledge. Conceptual models are open to modification as knowledge advances (based on entry in O'Toole, 2013 – Mosby's Medical Dictionary) – see Glossary and Appendix 2.

[11] An ontology for artificial intelligence is 'a representation of knowledge as a set of concepts and relationships that exist among those concepts' (Neapolitan and Jiang, 2018) – *s*ee Glossary and Appendix 2.

[12]Intelligence refers fundamentally and plainly to the capacity to acquire and apply knowledge and skills (Apple Dictionary app, Apple.com). This meaning need not refer exclusively to humankind and can cover the intelligence possible in living organisms and machines (see Glossary).

[13]Causal reasoning entails pathophysiological inference and looks to cause-and-effect relations that can be understood by an analysis of structure and function in health and disease (Kassirer et al., 2010)

The term evolutionary biology refers to activities that hinge on the particular meaning of evolution in biology and which explore where and how the theory of evolution by natural selection (evolution theory) may enhance knowledge across the life sciences. Note that the word 'evolution' is absent from the presentation to the Linnaean Society (Darwin and Wallace, 1858), which is seen as the first record of the concept of natural selection. Furthermore, Darwin referred to 'descent with modification', which is an apt descriptor and the word 'evolution' did not appear until the 6th edition of *Origin of Species*. 'Evolved', however, is the last word in the final and insightful sentence present in all editions.

> 'There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved'.

Darwin had a grasp of evolution as a phenomenon and a concept and this is put beyond doubt by an extract found under the heading, 'An Historical Sketch of the Recent Progress of Opinion on the Origin of Species'. The extract in question first appeared in the 3rd edition of the book and is shown below.

> 'Until recently the great majority of naturalists believed that species were immutable productions, and had been separately created. This view has been ably maintained by many authors. <u>Some few naturalists, on the other hand, have believed that species undergo modification, and that the existing forms of life are the descendants by true generation of pre-existing forms'</u>.

The words above align with definitions of evolution that appeared in the later 19th century and Darwin. Mivart (1871)[14] refers to evolution as 'new kinds being produced from older ones by the ordinary and constant operation of natural laws' and Wallace (1889) refers to evolution as the 'derivation of species from species by any natural law of descent'. As an aside, usage of the word 'law' in these contexts differs from the contemporary meaning of the word law in science. According to the National Academy of Sciences (1998), a law in science is a 'descriptive generalization about how some aspect of the natural world behaves under stated circumstances'. Nevertheless, the essence of evolution is succinctly expressed within the title of Darwin's *The Origin of Species by Means of Natural Selection*. The sixth edition refers to earlier accounts of the phenomenon that life forms change over time (Chapter 1), marshals evidence for this phenomenon and then sets out natural selection as the a cause of the phenomenon. Earlier accounts of changes in life forms over time that inspired Darwin's efforts include works by Lamarck (1801, 1809 and 1815), which like *Origin of Species* preceded August Weismann's (b. 1834, d.1914) germ-plasm theory (Weismann, 1892).

Weismann's book on germ-plasm, which opened the way to contemporary genetics, is dedicated to Charles Darwin and refutes the principle of variation (inheritance of acquired characteristics) proposed by 'the talented philosopher and investigator', Jean-Baptiste Lamarck (1809). On this point, Darwin's reference to 'use and disuse' in the last paragraph of *Origin of Species* reflects

[14] Mivart's book, 'On the Genesis of Species', sought to rebut the processes of descent with modification and natural selection.

Lamarck’s perception of inheritance and a quote from Bard (2022) is illuminating. ‘More than 100 years of research has shown that Darwin was right in almost everything he wrote other than the comment on use and disuse and emphasis on higher animals. What generations of evolutionary biologists have done is to add substance to the bare bones of Darwin’s mechanism of evolutionary change‘.

A distinction between a phenomenon (a fact or situation that is observed to exist or happen) and its cause leads into the idea of concept hierarchies that will guide the proposed ontology for the theory of evolution by natural selection (see section 2.4.3). In this regard, the phenomenon of evolution (the origin of species) ranks as a superordinate concept and the processes entailed in descent with modification and natural selection rank as subordinate concepts (see section 2.4.3, which discusses concept hierarchies). Romanes (1910) understood the notion of concept hierarchies and stated that organic evolution is a fact and natural selection is its cause. Facts and causes are distinctly different concepts that are sometimes confused. The notion of evolution as the phenomenon of changes over time in living organisms or life-forms has a long history that dates at least to the time of Empedocles (ca. 495–35 BCE)(Hull, 2002; Sloan, 2019; Smocovitis, 2016). As stated earlier, *Origin of Species* (Darwin, 1859-1872) made progress by systematising evidence around this longstanding acceptance of evolution as an observable fact. Darwin and Wallace proposed the concept of natural selection to explain how evolution comes about. This connection between evolution as an end and natural selection as the means to this end guides the structure of a concise and universally accessible ontology that suits the needs of One Health.

In general, the extensive literature around evolutionary biology does not provide a suitable technical account of natural selection theory that can be put to immediate practical use within One Health. The contrast with cell theory and the germ theory of disease in this regard is sharp. Cell theory has an immediate practical role as the platform for physiology and pathophysiology. The germ theory of disease enlightens an understanding of infectious diseases which include those caused by prions, viruses, bacteria (monerans), protozoa (protists), fungi and metoazoan endoparasites and ectoparasites. An issue here is that prominent works on the generalities of evolution have themes that are philosophical and social rather than practical and applied. Examples are Dawkins (1976, 1982, 1986), Dennett (1996) and Gould (2002), which link to issues of evolution and theology. These works have stimulated the wonder and curiosity that opens new thinking and accelerates the advancement of science (see AAAS, 1990) and can be read as part of the avocation or pastime reading recommended for medical professionals by William Osler in 1899 (McManus et al, 2011). They also mesh with biophilia, which is proposed as ‘the innate tendency to focus on life and lifelike processes’ or the innate urge of humans to ‘affiliate with other forms of life’ (Wilson, 1984). Biophilia can be reckoned to inspire participants in One Health. Other books with a social and philosophical theme address topics related to evolutionary biology and religion (Ayala, 2007 and Malik, 2021).

Some words from Rovelli (2020) that describe the two-way relationship between science and philosophy are important for managing and making sense of the diverse literature around evolution:

'A science that closes its ears to philosophy fades into superficiality; a philosophy that pays no attention to the scientific knowledge of its time is obtuse and sterile'. In classical times, Aristotle (384-322 BCE) distinguished 'philosophical reflection on a discipline from the practice of a discipline itself' (Irwin, 2000). Aristotle's distinction between science and philosophy operates within the present discourse. Dictionary definitions put philosophy as 'the study of the fundamental nature of knowledge, reality, and existence' (Apple Dictionary, version 2.2.2[15]) or the 'systematic examination of basic concepts such as truth, existence, reality, causation and freedom' (Rooney, 1999). Science is defined in these places as the 'intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment' (Apple Dictionary, version 2.2.2) or the 'study of the physical world and its manifestations especially by using systematic observation and experiment' (Rooney, 1999).

These points on philosophy and science serve to introduce some thoughts about science and religion and then about science and evolutionary biology. Darwin referred to William Whewell's Bridgewater Treatise (Whewell, 1839) in every edition of *Origin of Species* and the notion that 'events in the material world are brought about by general laws' and 'not by insulated interpositions of Divine power, exerted in each particular case'. Support for this viewpoint comes from the christian clerics Robert Grosseteste (1168 – 1253 CE), Albertus Magnus (1200 -1280 CE) and Thomas Aquinas (1224-1274 CE). Robert Grosseteste expounded the view that the material world is knowable and that God operates through natural laws and rational order the importance of empirical study, and the use of mathematics in understanding the universe. Albertus Magnus emphasised the importance of studying the natural world to understand God's creation and proposed that nature was an expression of God's rational order and that human reason could uncover the principles underlying it (Grant, 1966).

Further support for the view that the material world is knowable and that the deity (Allah) operates through natural laws comes from the Islamic scholars Al-Farabi (872 – 950 BCE), Ibn Sena (980 – 1037 BCE), Al-Ghazali (1058 – 1111 BCE), Ibn-Rushd (1126 – 1198 BCE), Al-Buruni (973 – 1048 BCE) and Ibn Kaldun (1132 – 1046 BCE)(Nasr, 1968). These scholars are said to have set the scene for harmony for between science and theology in Islamic and Western thought for centuries to come.

The view that the material world is knowable and that divinity acts through natural laws is reinforced more recently by Pope Francis (2015) in the encyclical *Laudato Si'* (2015)[16], which calls for concerted action against climate change. Pope Francis states that regard for the natural laws which sustain ecosystems expresses love and urges humanity to act as responsible stewards of creation.

By and large, religions have moved towards the view that evolutionary biology can reconcile with beliefs. A website of the National Academies of Sciences, Engineering, and Medicine of the USA

[15] https://support.apple.com/en-au/guide/dictionary/welcome/mac

[16] https://www.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.html

(https://www.nationalacademies.org/evolution/science-and-religion) informs on this matter and other support comes from Ayala (2007) and Malik (2023). Ayala (2007) sets out a case that that natural selection theory can resolve the problem of theodicy by shifting the responsibility for natural evils (such as suffering, disease, and death) away from God and attributing them to natural processes. Theodicy concerns the conundrum that if God is good and all-powerful, why does evil exist? Ayala's theme is extended by Haught (2000). Malik (2021) arrays a set of ideas that allow for harmony between Islam and contemporary 21st Century non-adversarial accounts of natural selection theory. Earlier accounts of natural selection theory that trend towards malign social Darwinism are likely to hamper engagement.

Advances in biological understanding since the time of the so-called 'modern evolutionary synthesis' of the 20th Century (see Bowler, 1989) are an additional consideration for the practical application of evolutionary biology. For example, the actuality of prions as evolvable proteins (Lindquist, 1997; Wickner, 1997) and the character of viruses[17] as infectious agents 'at the edge of life' (Rybicki, 1990; Murphy et al., 1999) came onto the scene only in the 1990s. Viroids and virusoids, which are pathogens of plants (Diener, 2003; Ding, 2009), are a further concern. So, the theory of evolution by natural selection (evolution theory), which was initially conceived for cellular organisms[18], must now explicitly accommodate viruses and prions, which are sub-cellular life-forms (see section 4.2). In this regard, the theory of evolution by natural selection has a history of advancement (Futuyma and Kirkpatrick, 2017) from the time of Darwin and Wallace to the time of so-called neo-Darwinism and is open to further refinement and clarification in the light of advancing knowledge like that related to viruses and prions. Knowledge around mobile genetic elements, epigenetics and so on has prompted development of a so-called extended evolutionary synthesis (Laland et al., 2015; Műller, 2017), inclusive evolutionary synthesis (Corning 2020) or a third way of evolution (Shapiro and Noble, 2021).

The centrepiece of this effort to translate the theory of evolution by natural selection (evolution theory) and evolutionary biology for use in One Health is a particular version of a conceptual framework known as an ontology, which is an ordered sequence of concepts employed in computer technology, software engineering and artificial intelligence (Russell and Norvig, 2010; Neapolitan and Jiang, 2018). An ontology provides an opportune means for expediting the application of evolutionary biology within One Health and mitigating possible language barriers.

Important background for the present task comes from the continuing challenge of zoonotic epidemics, for example those caused by rapidly evolving RNA viruses such as the orthomyxoviruses (influenza) and the coronaviruses (SARS, MERS, COVID-19), and the clear-cut imperative for enhancing the global impact of veterinary services and One Health as a whole. The point is that emerging infections like COVID-19 are a 'perpetual challenge' (Morens et al., 2008)

[17] Tobin and Morel (1997) state that viruses are assemblies of protein and nucleic acid (sometimes with lipids and carbohydrates) that can reproduce only within living cells and which depend on cells to obtain energy and perform chemical reactions.

[18] Tobin and Morel (1997) state (1) that living organisms consist of well-ordered parts, obtain energy from their surroundings, perform chemical reactions, change with time, respond to their environments, reproduce, and share parts of a common history and (2) that cells are the fundamental living unit of all organisms.

with root causes that include agricultural and land-use practices, ecosystem and climate change, and the vast array of human activity (Morens et al., 2004; Morse, 2004; FAO, 2011; FAO, 2013a). Factors influencing where and how the theory of evolution by natural selection situates within One Health are found within the scope of (1) international affairs, (2) economics, and (3) ethics. Other matters for consideration then follow. These are (4) the practices and processes of communication within and about science, (5) the translation and extension of knowledge and skills, (6) an understanding of the role of theories and laws within science, and (7) the value of reciprocity and knowledge sharing within and between One Health and the field of evolutionary biology.

The historical context for a renewed version of the theory of evolution by natural selection is explored in Section 3. Here, certain foundational words such as 'theory', 'natural' and 'nature' are probed for their meanings and interrelationships from the time of Darwin and Wallace to the present day.

2.1 An ontology for expounding the theory of evolution by natural selection

The single consideration for sifting material within evolutionary biology is whether it is relevant to clinical reasoning or critical thinking within One Health[19]. Relevance extends to the proposed ontology for the theory of evolution by natural selection. Ontologies and algorithms complement one another within the field of information technology. Ontologies provide a structured representation of knowledge within an area of interest and algorithms are step-by-step procedures for solving problems or performing a tasks. Ontologies provide the context and meanings of terms that guide how an algorithm interprets or manipulates data. An ontology presents as an inclusive and intelligible system for exploring ideas about how the theory of evolution by natural selection[20] and its extensions and implications can mesh with medicine, pathology, epidemiology, ecology and agriculture and have practical application across the globe. The essential starting point is choice of a present-day and precising definition for the phenomenon of evolution that can shape the proposed ontology for natural selection theory. This precising definition was sought through a sample of 18 definitions of or short statements about evolution shown in Table 1 and aims at reducing the vagueness of the term. Different shades of meaning and different perspectives are apparent within these 18 entries. Nevertheless, all seem to converge on the same central theme and general concept for the phenomenon of evolution.

Notions of macroevolution and microevolution are not required for the definition of evolution sought via Table 1. Macroevolution and microevolution are terms used to denote areas of interest within evolutionary biology and have no implications for the substance of the theory of evolution by natural selection. Zimmer and Emlen (2016) describe macroevolution as evolution occurring

[19]Some sources have been ruled out for this reason.

[20]Two of the three major theories in biology (according to the sense of 'theory' used for science) are cell theory and germ theory. These are named by prefixing 'theory' with the noun adjuncts, cell and theory. For consistency, the theory of evolution by natural selection, the third major theory in biology, can be shortened to theory of evolution by natural selection. This practice occurs within the German language where germ theory is Keimtheorie, cell theory is Zelltheorie and the theory of evolution by natural selection is Evolutionstheorie.

above the species level, including the origination, diversification, and extinction of species over long periods of evolutionary time and microevolution as evolution occurring within populations, including adaptive and neutral changes in allele frequencies from one generation to the next. Gluckman et al (2017) state that the subject of macroevolution, the process underpinning speciation and biodiversity, is not central to a medical perspective. Biodiversity, however, is a concern for One Health and macroevolution can provide important insights. Biodiversity determines how ecosystems function to produce the ecosystem services that sustain human wellbeing and economic value (Paul et al., 2020). Ecosystem function refers to transfers of energy, material, organisms or information among its parts. A perspective that links evolution and thermodynamics may open opportunities for appraising the health and integrity of ecosystems and the resilience and sustainability of ecosystem services (Nielsen et al, 2020). The key here is that life at all levels and in all forms concerns exchanges of matter and energy and is governed by the laws of thermodynamics (Schneider and Sagan, 2005). A thumbnail of thermodynamics and its associated laws is provided in the Glossary.

Table 1: Selected definitions of the term 'evolution'.

	Source	**Definition**
1,	Abercrombie M, Hickman CJ and Johnson ML (1957) *A Dictionary of Biology.* Penguin Books, Harmondsworth.	Cumulative changes in the characteristics of populations of organisms, occurring in successive generations related by descent. The theory that evolution accounts for origin of all kinds of organisms now existing is opposed to the theory of special creation, i.e. that each kind of organism was created as such and is not related by descent to any other.
2.	Grove AJ, Newell GE and Carthy JD (1961) *Animal Biology.* University Tutorial Press, London.	………in the natural world there has been in operation a process called **Organic Evolution.** By this process, the present-day forms have arisen by gradual changes from pre-existing forms, unlike them in many features, so that it may be said that the more complex have been derived from the simpler and that the animal kingdom can be viewed as a series of progressively increasing complexity.
3.	Raven PH, Evert RF and Eichhorn SE (1992) *Biology of Plants, Fifth Edition*. Worth Publishers, New York.	The derivation of progressively more complex forms from simple ancestors.
4.	Richards RJ (1992) Evolution. In: *Keywords in Evolutionary Biology* (Edited by Keller EF and Lloyd EA). Harvard University Press, Harvard, Massachusetts.	The term ‘evolution’ as we now use it, commonly refers to change of species over time and is usually associated with Darwin’s theory of the descent of species by natural selection. The word did not always carry this set of specific meanings and associations. The term may itself be regarded as an evolved product, which reached its present state through descent with modifications induced by conceptually selective forces. Accordingly, its older meanings yet lie below the surface still gently affecting the term’s significance.

5.	National Academy of Sciences, Working Group on Teaching Evolution, (1998) *Teaching About Evolution* and *the Naure of Science*. National Academies Press, Washington DC.	Change in the hereditary characteristics of groups of organisms over the course of generations. (Darwin referred to this process as 'descent with modification')
6.	Freeman S and Herron SC (2001) *Evolutionary Analysis, Second Edition.* Prentice Hall, Upper Saddle River, New Jersey.	Originally defined as descent with modification, or changes in the characteristics of populations over time. Currently defined as changes in allele frequency over time.
7.	Hickman CP et al (2006) *Integrated Principles of Zoology, Thirteenth Edition*. McGraw Hill, New York.	Organic evolution encompasses all changes in the characteristics and diversity of life on earth throughout its history.
8.	Mayr E (2001) *What Evolution Is*. Basic Books, New York.	The gradual process by which the living world has been developing following the origin of life.
9.	Campbell NA and Reece JB (2002) *Biology, Sixth Edition.* Benjamin Cummings, San Francisco.	All the changes that have transformed life on Earth from its earliest beginnings to the diversity that characterizes it today.
10.	Ridley M (2004) *Evolution, Third Edition*. Blackwell Publishing Company, Oxford.	Darwin defined it [evolution] as 'descent with modification'. It is the change in a *lineage* of *populations* between generations.

Most of the statements shown in Table 1 are reckoned as superordinate, over-arching or umbrella definitions according to the crucial notion of concept hierarchies (see section 2.4.3) and in the sense that they define the phenomenon of evolution at the organisational level of the cell and above. Exceptions are those of Freeman and Herron (2001) and Hall and Hallgrimson (2007), which qualify as subordinate definitions in the sense that they portray evolution as 'changes in allele frequencies over time' or 'genetic changes' and below the organisational level of the cell.

The following precising definition of evolution as a phenomenon has been synthesised from entries in Table 1 and will be applied to the proposed ontology for the theory of evolution by natural selection. It equates to Darwin's insightful phrase, 'descent with modification', which has given rise to the evolutionary algorithms employed in information and computer technology[21]. Note that evolution stands above macroevolution and microevolution, which compose a continuum and are not distinct entities (Gluckman et al., 2017). These terms refer to fields of interest in evolutionary biology and do impinge on the substance of the theory of evolution by natural selection. Accordingly, they are not necessary for unravelling Darwin's view of evolution as the result of 'laws acting around us'), including 'variability from the indirect and direct action of the "conditions of life" '. The phrase 'laws acting around us' is reworded for present use as 'factors operating around us' to account for the current meaning laws in science as as statements of a relation or sequence of phenomena invariable under the same conditions, as in the Newton's Laws of Motion (see section 2.4.2). The phrase 'conditions of life' merges elements in both life forms and the environment and is as detailed in Chapter 3 (section 3.4.3) and reiterated in Chapter 5. The 'conditions of life' that give rise to variability are factors within life forms that generate variants or

[21]Evolutionary Algorithm. https://en.wikipedia.org/wiki/Evolutionary_algorithm

‘an individual or species deviating in some character or characters from type’ (Lawrence, 2008) and factors external to the life form that test the viability of a variant. A two-component structure of Darwin’s ‘conditions of life’ is apt for the proposed ontology which sees natural selection as the result of interactions between the nature or intrinsic characteristics and properties of a life form and those of their environment.

> *The phenomenon of evolution exists in the understandable physical world and refers to changes (modifications) over successive generations in the hereditary characteristics (traits) of populations (groups) of cellular organisms or sub-cellular life forms such as viruses, prions and the viroids and virusoids occurring in plant that are related by* descent *(lineage) and which extends to and includes all levels in the organisation spectrum from genetic systems to ecosystems.*

Passage of time is implied by the phrase ‘over successive generations’. The word ‘successive’ captures the idea that change builds upon previous change and reflects that actuality of life cycles as events in the existence of a life form from its formation to an equivalent stage in the next generation. The word 'heredity' is broad in compass and covers all aspects of inheritance and genetics. Words such as (1) ‘population’ and ‘group’, (2) ‘characteristics’ and ‘traits’ and (3) ‘descent’ and ‘lineage’ can be regarded as somewhat interchangeable. The phrase ‘understandable real world’ reflects the tenet of science that things and events in the universe occur in consistent patterns that are comprehensible through careful, systematic study (AAAS, 1989). In addition, the phrase reinforces Darwin’s reference to William Whewell’s Bridgewater Treatise (Whewell, 1839) and the notion that ‘events in the material world are brought about by general laws’ and ‘not by insulated interpositions of Divine power, exerted in each particular case’. Operation of evolution at the level of genetic systems has implications for the management of neoplasia. Operation of evolution at at the level of ecosystems has implications for natural resources management.

The term evolvability which derives from the noun, ‘evolution’, and the verb, ‘to evolve’, surfaced in discussions around evolutionary biology during the 1990s. It has a plain meaning as the ability of an entity to evolve or undergo evolution and has been described as a unifying concept in evolutionary biology (Hansen et al., 2023). Accordingly, evolvability is self-evident wherever the words ‘evolve’ or ‘evolution’ are mentioned and will operate silently within the proposed ontology for the theory of evolution by natural selection.

Evolution stated as a phenomenon distinguishes it categorically from natural selection stated as a process. This semantic distinction is critical to the sort of conceptual framework for the theory of evolution by natural selection that uses the notion of an ontology applying to computer technology, software engineering and artificial intelligence (Russell and Norvig, 2010; Neapolitan and Jiang, 2018). It is noteworthy that the field of artificial intelligence within software engineering uses so-called evolutionary computation which is based on the evolutionary mechanisms applying to natural selection in biology (Neapolitan and Jiang, 2018). The word ‘organism’ in the proposed ontology

has been defined as any living thing (Lawrence, 2008) and thus can encompass life forms such as viruses and prions.

The terms intelligence and ontology require clarification. The American Psychological Associations refers to intelligence as the ability to derive information, learn from experience, adapt to the environment, understand, and correctly utilize thought and reason (VandenBos, 2015). The term intelligence is elaborated for application within computer technology and software engineering by Russell and Norvig (2010), Negnevitsky (2011), Ertel (2017) and Neapolitan and Jiang (2018). Kaplan and Haenlein (2019) refer to artificial intelligence as a hazy concept with many unanswered questions and provide the following precising definition: ‘A system’s ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation’. This precising definition is put more simply as the ability to learn coupled with flexibility in behaviour (Burnie, 2001). Houpt (2011) describes how the term ‘intelligence’ can be deployed for practical application with domestic animals. McFarland (2006) explored possible qualifications to the use of the term ‘intelligence’ within the discipline of ethology (animal behaviour). Intelligence as the ability to learn, know and respond to the environment is apparent in vertebrates and other life forms such as arthropods (Cross et al., 2020), cephalopods (Amodio et al., 2019) and slime moulds (Reid and Latty, 2016).

As to ontology, this term is used within artificial intelligence to describe ‘a representation of knowledge as a set of concepts and relationships that exist among those concepts’ (Neapolitan and Jiang, 2018). Put simply, an ontology is an orderly sequence of concepts. Concepts within an ontology for natural selection theory flow as a hierarchy from phenomenon to theory, agency, process, ability (capability, capacity), and then to structure, function and mechanism integrated and actuated by organisation. Ability (capability, capacity) implies the possession of adaptations or ‘any peculiarity, property or feature of the structure, physiology or behaviour of an organism or biological entity, such as a virus or prion, that enables it to be viable and to survive and reproduce in a particular environment’ (precising definition from section 3.4.5). Definitions of these concepts that suit the proposed ontology and conceptual framework for the theory of evolution by natural selection have been selected from four sources and are set out in Table 2 where they are listed sequentially from the superordinate to successive subordinate concepts. In short, phenomena have explanatory theories and result from agency which, in turn, builds upon chains of causation derived from an organisation of component causes (processes, capabilities, adaptations, structures, functions and mechanisms) into a causation unit. Figure 1 is a diagram that shows connections in a generic concept hierarchy applicable to natural selection theory, cell theory and germ theory. Table 2 provides the essence of each concept shown in Figure 1.

Dubois (2007) states that ‘more than a century ago, the French physiologist Claude Bernard gave a clear formulation of the now classical view that the earmark of a living thing is not the chemical composition of its parts but their organization’. The whole causation unit is indeed ‘greater than the sum of its parts’ because it results from the integration and combination of its parts and not their summation. As to structures, Konieczny et al (2023) introduce a distinction between support

structures (which are akin to construction materials), function-related structures (fulfilling the role of tools and machines), and storage structures (needed to store important substances, achieving a compromise between tight packing and ease of access).

Table 2: Definitions of terms used in a concept hierarchy guiding an ontology for evolution theory

Rank in concept hierarchy	Definition
1. SUPERORDINATE CONCEPT Phenomenon – Evolution or descent with modification.	Any fact, circumstance or experience that is apparent to the senses and that can be scientifically described or appraised, as an eclipse (Webster's). A fact, occurrence, or circumstance observed or observable (Macquarie). Something that is observed to happen or exist (Collins). Thing that appears or is perceived (Concise Oxford).
2. SUBORDINATE CONCEPT 1. Theory - as in the theory of evolution by natural selection (evolution theory).	An explanation and interpretation of a phenomenon or aspect of the natural world.
3. SUBORDINATE CONCEPT 2. Agency	That by which something [such as evolution] is done or achieved (Webster's) and according to the organisation and nature of component causes that constitute Subordinate Concept 3. Agency is inspired by the substance of a theory.
4. SUBORDINATE CONCEPT 3. Causation unit (inclusive)	System of overlapping causal factors or component causes (compound of component causes) that energise agency and, for example, drive evolution in life forms.
5. SUBORDINATE CONCEPT 4. Causation unit (environment)	Causal factors derived from Nature A (Essence) of the environment.
6. SUBORDINATE CONCEPT 5. Causation unit (life form)	Causal factors derived from Nature A (Essence) of the life form.
7. Factors and concepts in SUBORDINATE CONCEPTS 4, 5 and 6 that constitute a compound of component causes or causation unit.	
(1) Organisation: The structured arrangement and interaction of components within a system that determines how structure, function and mechanism integrate to produces capabilities that generate agency or the means by which something is accomplished. (2) Process: i. A particular method of doing, achieving or arriving at something, generally involving a number of steps or operations (Webster's Collegiate Dictionary). ii. A continuous action, operation, or series of changes taking place in a definite manner (Macquarie Dictionary). iii. A series of actions which are carried out in order to achieve a particular result (Collins Dictionary). iv. Course of action, proceeding (Concise Oxford Dictionary). (3) Capability: Abilities, capabilities and capacities (components of processes).: *Ability*: Being able, power to do (Webster's Collegiate Dictionary). The power or capacity to do or act in any relation (Macquarie). Being able; power to do (Collins). Sufficient power, capacity to do something (Concise Oxford). *Capability*: The quality of being capable or having ability (Webster's). The quality of being capable, capacity, ability (Macquarie). The quality of being capable; practical ability (Collins). Power of action (Concise). *Capacity:* The quality of of being adapted (*for* something) or susceptible (*of* something)(Webster's). The power,	

ability, or possibility of doing something (Macquarie) .The ability to do or produce (Collins). Capability to do something (Concise Oxford Dictionary).

(4) Adaptation:
i. Any peculiarity, property or feature of the structure, physiology or behaviour of an organism or biological entity, such as a virus or prion, that enables it to survive and reproduce in a particular environment.
ii. Adaptations can be depicted as the capabilities that underpin viability and reproduction (precising definition).
iii. Adaptations integrate structure, function and mechanism by means of organisation (see Glossary).
(5) Structure (form):
Structure: The arrangement or interrelation of all the [physical] parts of a whole (adapted from Webster's)
Form: The way the physical components of a whole are organized (adapted from Webster's).
(6) Function:
i. The normal or characteristic action of anything; esp., any of the natural, specialized actions of an organ or part of an animal or plant (Webster's).
ii. The kind of action or activity proper [pertaining] to a person, thing or institution (Macquarie).
iii. The normal or characteristic action of anything; esp., any of the natural, specialized actions of a system, organ, or part of an animal or plant (Collins).
iv. Activity proper to anything, mode of action by which it fulfils its purpose (Concise Oxford).
Activity and role assigned to something (Rooney, 1999)
(7) Mechanism:
i. The way something works (Rooney, 1999).
ii. An instrument or a process, physical or mental, by which something is done or comes into being (American Heritage Dictionary, https://ahdictionary.com/word/search.html?q=mechanism).

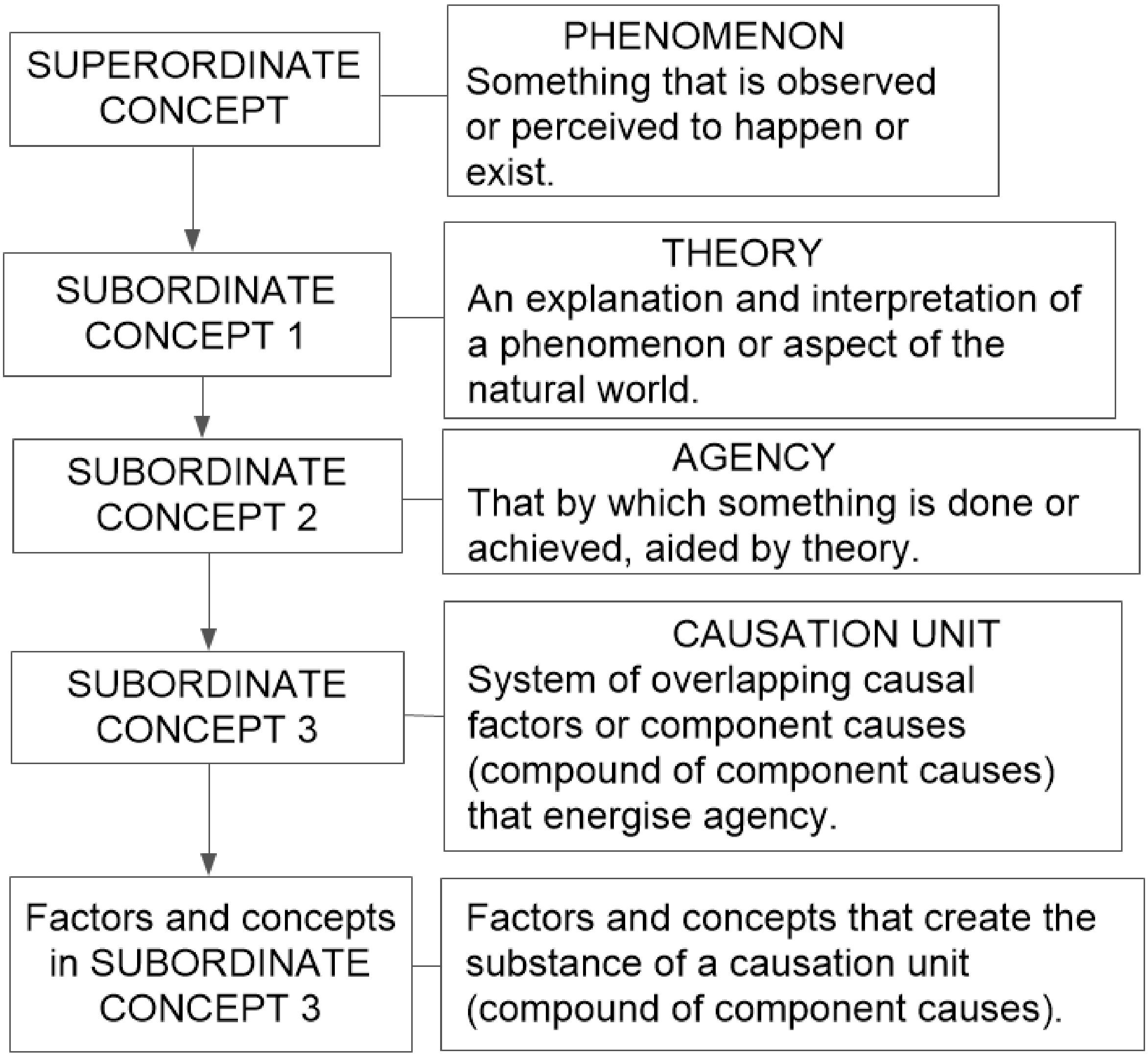

Figure 1: Diagram showing connections in a generic concept hierarchy that can apply to evolution theory, cell theory and germ theory and guide the ontology for evolution theory.

2.2 A perspective from international affairs: solidarity

Epidemics and pandemics require a level of international solidarity that generates co-operative, transparent, science-based, and globally coordinated actions for prevention, control, management and recovery (WHO, 2020b; Alliance for Multilateralism, 2020). The basics are outlined in the FAO/OIE/WHO Tripartite Collaboration (FAO, OIE and WHO, 2017), which advocates for effective, multi-sectoral collaboration at local, national, regional and global levels founded on 'One Health'. The Tripartite Collaboration, which has developed into the One Health Action Plan (2022-2026) recognises that the health of people, animals and the environment is intertwined and that 'the combined knowledge, insights and technical capacities in food, agriculture, and human and animal health can generate strong synergies, which will yield more robust, effective and cost-efficient solutions to the complex problems facing the world today'. 'Combined knowledge', as outlined in

the Tripartite Collaboration and the One Health Action Plan (2022-2026), inspires the present effort, which builds from the whole of biology and embraces contributions from many other disciplines such as economics, ethics, linguistics (including communication studies) and history.

The idea of 'solidarity' is fundamental to One Health and merits further attention. A review of the term comes from Prainsack and Pruyx (2011) who propose that 'solidarity signifies shared practices reflecting a collective commitment to carry 'costs' (financial, social, emotional or otherwise) to assist others'. Solidarity is seen as a 'practice and not merely as an inner sentiment or an abstract value" that "requires actions" and that "motivations, feelings such as empathy etc. are not sufficient to satisfy this understanding of solidarity, unless they manifest themselves in acts'. The precising definition of solidarity proposed by Prainsack and Pruyx (2011) consists of three tiers relating to interpersonal relations, group actions and legal considerations.

2.3 A perspective from economics

As to economics, there is a defensible case that activities in public health against infectious diseases (for example, COVID-19) should classify as global public goods because the effectiveness of public health measures requires international cooperation (Brown and Susskind, 2020). To explain, Samuelson and Nordhaus (2009) describe a public good as 'a commodity whose benefits are indivisibly spread among the entire community, whether or not particular individuals desire to consume the public good. For example, a public-health measure that eradicates polio protects all, not just those paying for the vaccinations. To be contrasted with private goods, such as bread, which, if consumed by one person, cannot be consumed by another person'. Kaul and Mendoza (2003) describe global public goods as 'goods with benefits and/or costs that potentially extend to all countries, people, and generations'. They go on to say that 'global public goods are in a dual sense public: they are public as opposed to private; and they are global as opposed to national'.

Like human public health services, veterinary services classify as global public goods because they 'contribute directly and indirectly to food security and to safeguarding human health and economic resources'(Eloit, 2012). Furthermore, activities against infectious diseases of animals such as African swine fever require international cooperation in a manner similar to diseases of people. The designation of veterinary services as a global public good applies likewise to all activities associated with One Health-Planetary Health. Notions of public good lie at the heart of international bodies like the Food and Agriculture Organization and the World Bank Group and guide their aspirations to advance the health and wellbeing of people through good nutrition and its roots in responsible agriculture and sound resources management (FAO, 2007a; FAO, 2103a; FAO, 2013b; FAO, 2014; FAO, 2018; World Bank, 2015; World Bank, 2016; World Bank, 2018). Falvey (2020) argues that the globalisation of knowledge makes access to safe and healthy food and access to clean water a 'public good and a right for all persons in the world'which requires 'respect for the means by which all persons can access sound nutrition that avoids such afflictions as blindness, curbed mental development and physical stunting'. Falvey (2020) goes on to say that all this is 'not just the responsibility of agricultural science but of all who are well-fed and wealthy'.

Knowledge in the broad qualifies as a global public good (Stiglitz, 1999). This proposition is highly relevant to the creation of a simple, concise and inclusive account of the theory of evolution by natural selection. Stiglitz (1999) states that 'a mathematical theorem is as true in Russia as it is in the United States, in Africa as it is in Australia'. The theory of evolution by natural selection will be true in like manner but may not be intelligible across national boundaries if there are impediments related to language and flawed translations. Public goods have the character of being 'non-excludable', that is their use cannot be reserved for some and must be available to all (Eloit, 2012). Non-excludability for the theory of evolution by natural selection and its status as a global public good can be safeguarded by making it universally intelligible.

2.4 A perspective from ethics and the practice of science

2.4.1 Ethics

Two matters of ethics are considered for the theory of evolution by natural selection and its application in One Health. Ethics refers to systems or theories of moral values and it is anticipated that generalities in the system of moral values applying to health care professionals (Berglund, 2007) can apply universally. With this in mind, the first consideration derives from the principles of beneficence, non-maleficence, autonomy and justice promulgated by Beauchamp and Childress (1994)[22] in the Belmont report of 1979, which can extend from medical research to the whole of One Health. The second consideration relates to the obligation of health care professionals to maintain and develop skills. This second consideration can also apply throughout efforts towards One Health.

As to the first consideration, non-maleficence (the principle of not harming others as in the Hippocratic maxim of *primum non nocere,* above all [or first] do no harm) justifies some reticence about evolutionary biology because of its historical association with maleficent social beliefs like racism, social Darwinism and eugenics (documented by Bajema, 1976; Kevles,1985; Carlson, 2001). The rhetoric directed at reincarnating social Darwinism and eugenics under the label of 'scientific humanism' or 'evolutionary humanism' (Huxley, 1957; Huxley, 1961; Huxley, 1964) must be included here both for its maleficence and unsound biology (see Weindling, 2012). Principles of respect for autonomy or allowing people to make decisions about their own lives and social justice also argue against acceptance of eugenics by health care professionals. Levine and Bashford (2010) state that eugenics always had 'an evaluative logic at it core. Some human life was of more value – to the state, the nation, the race, future generations – than other human life and thus advocates sought to implement these practices differentially'.

Alfred Russel Wallace, the co-founder of theory of evolution by natural selection, rejected eugenics and the related social Darwinism. This is demonstrated by the following statement: 'The world does

[22]These principles appear in the Belmont Report published in 1979 by the US Department of Health and Human Services (https://www.hhs.gov/ohrp/regulations-and-policy/belmont-report/read-the-belmont-report/index.html).

not want the eugenicist to set it straight. Give the people good conditions, improve their environment, and all will tend toward the highest type. Eugenics is simply the meddlesome interference of an arrogant, scientific priestcraft' (see Durant, 1979). Mayr (2001) defines social Darwinism as 'a political theory postulating that ruthless egotism is the most successful policy'.

Darwin's own views on social Darwinism and eugenics are unclear. Statements about the capabilities of women and indigenous Americans and Australians within all editions of *Descent of Man* (Darwin, 1871, 1874 and 1889) connote a racist and sexist view of humanity that might justify certain nineteenth century views about social rankings, empire and colonialism, and genocide (Fuentes, 2021). Fuentes (2021) goes on to say that 'We can acknowledge Darwin for key insights but must push against his unfounded and harmful assertions'. The conundrum here is that Darwin's diary of the *Voyage of the Beagle* (Darwin, 1860) demonstrates a compassion for aboriginal people that runs against the mindset of social Darwinism. Darwin observes that: 'Wherever the European has trod, death seems to pursue the aboriginal. We may look to the wide extent of the Americas, Polynesia, the Cape of Good Hope, and Australia, and we find the same result'. He is also concerned that the plight of Tasmanian aboriginals 'originated in the infamous conduct of some of our countrymen' and that 'thirty years is a short period, in which to have banished the last aboriginal from his native island'. Fuentes (2021) states that *Descent of Man* is a 'text from which to learn, but not to venerate'. Regardless of 'his unfounded and harmful assertions' in *Descent of Man*, Darwin merits unreserved gratitude and respect for his prodigious efforts, including his *Origin of Species* and his exposition of the theory of evolution by natural selection.

According to current practice for systematic reviews (Institute of Medicine, 2011), *Descent of Man* may have historical importance but does not meet quality requirements for systematic reviews (Institute of Medicine, 2011) and will not assist in designing a user interface between the theory of evolution by natural selection and One Health. The quality control idea of a defect (Evans and Lindsay, 1989) is used for evaluating whether items of literature within evolutionary biology can contribute to the reliability of this user interface. In this connection, minor defects in quality control are small, insignificant issues that don't affect the function or form of a product. Major defects affect the function, form or appearance of a product. Critical defects make a product unusable and a possible source of harm. Critical defects are present in *Descent of Man* and are demonstrated by a multitude of unsafe and unsupportable statements such as that on page 62: 'On the other hand; as Büchner (footnote 48) has remarked, how little can the hard-worked wife of a degraded Australian savage, who uses hardly any abstract words and cannot count above four, exert her self-consciousness, or reflect on the nature of her own existence'.

The second consideration around ethics relates to the principle of beneficence, which concerns the doing of good and providing for others (Berglund, 2007). Doing good and providing care are actions requiring skills that are supported by reliable knowledge. 'The skills aspect of professional work is is inextricably linked to professional ethics' (Berglund, 2007). Reliable knowledge itself comes from disinterested reflection and analysis. Disinterestedness along with communalism, universalism and organised scepticism make up the four sets of institutional imperatives that can

guide the ethos of science (Merton, 1942)[23]. Writing founded upon eugenics and social Darwinism and not upon a disinterested accounting of biology can be a source of unreliable and unsafe knowledge for One Health.

An extract from a report titled, *On Being A Scientist* (National Academy of Sciences, 2009), captures the essence of disinterestedness or impartiality within the practice of science and is shown below.

> 'Strongly held values or beliefs can compromise a person's science in some instances. The history of science offers a number of episodes in which social or personal beliefs distorted the work of researchers. For example, the ideological rejection of Mendelian genetics in the Soviet Union beginning in the 1930s crippled Soviet biology for decades. The field of eugenics used the techniques of science to try to demonstrate the inferiority of particular human groups, according to nonscientific prejudices.
>
> Despite such cautionary episodes, it is clear that all values cannot—and should not—be separated from science. The desire to do good work is a human value. So is the conviction that standards of honesty and objectivity must be maintained. However, values that compromise objectivity and introduce bias into research must be recognized and minimized'.

2.4.2 Science

Science, seen as a body of knowledge and ways of thinking and acting in the pursuit of knowledge (Sagan, 1995; Gauch, 2003; Hohenberg, 2010) is served by laws and theories. Laws in science describe or predict various phenomena in nature and are defined as statements of a relation or sequence of phenomena invariable under the same conditions (*Macquarie Encyclopedic Dictionary*; Delbridge, 1990). According to the National Academy of Sciences (1998), a law in science is a 'descriptive generalization about how some aspect of the natural world behaves under stated circumstances'. The laws of physics (exemplified by the laws of thermodynamics and motion) and the laws of chemistry (exemplified by gas laws and chemical transport laws) apply to life forms and make biology comprehensible. This position conforms to ideas of the unity of science and reductionism that operate in philosophy. The unity of science states that 'all sciences share the same language, laws and methods' (Ruse, 1995). Reductionism, described as 'one of the most used and abused terms in the philosophical lexicon', has been used in the past to disparage and discredit. However, so-called methodological reductionism proposes that the 'best scientific strategy is always to attempt explanation in terms of even more minute entities' (Ruse, 1995).

[23] Merton (1942) proposed that four CUDOS principles can guide the ethos of science. These principles are restated as follows: 1. **Communalism** [stated as Communism by Merton] where scientists have equal access to scientific goods (intellectual property), and sense of common ownership promotes cooperation with no secrecy (c.v. solidarity, global common goods and One Health).; 2. **Universalism** all scientists can contribute to science regardless of race, nationality, culture, or gender (c.v. solidarity, justice, equity and One Health). 3. **Disinterestedness** where scientists act for the benefit of a common scientific enterprise, not for personal gain (c.v. solidarity, common good, professionalism and One Health). 4. **Organized Skepticism** where scientific claims are open to critical scrutiny and science's practice of refutation and falsification (Popper, 1963).

According to publications from the National Academy of Sciences of the USA, theories in science are intelligible as ‘well-substantiated explanations of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses’ (National Academy of Sciences 1998). or ‘comprehensive explanations of aspects of nature that are supported by vast bodies of evidence such that that they can be used to make predictions about natural events or phenomena that have not yet been observed’ (National Academy of Sciences, 2008). Theories differ from laws in laws by proposing structured explanations that can be modified or elaborated as knowledge develops (Mayer and Gamble, 2024). A prime example from the physical sciences is the atomic theory. Atomic theory as proposed by John Dalton (1808) explains the basic tenets of chemistry, allows an understanding of matter and facilitates explanations and predictions about life forms. The attributes of life (responsiveness, growth, metabolism, energy transformation, and reproduction) are founded upon chemical mechanisms (https://digital.sciencehistory.org/works/ff365590j).

Origin of Species (Darwin, 1872) predates a threshold understanding of the chemical mechanisms that generate life and deviates from the current usage of the term ‘law’ within science. The last paragraph of this book sums up the results of natural selection as having ‘all been produced by laws acting around us’. The ‘laws acting around us’ refers to the processes involved in natural selection and the results or phenomena observed in the ‘tangled bank’ ecosystem[24]. As stated earlier, the phrase ‘laws acting around us’ is reworded for present use as ‘factors operating around us’ to account for the current meaning laws in science as as statements of a relation or sequence of phenomena invariable under the same conditions, as in the Newton’s Laws of Motion (see section 2.4.2).

Darwins ‘laws [factors] acting around’ are renewed according to present day knowledge and provide raw material for the ontology or concept network making up the proposed conceptual framework or the theory of evolution by natural selection. These factors will be represented in the flow of concepts in the ontology, which descend from phenomenon, to process, capability (capacity or ability that begins with viability or the ability to live or survive), structure, function (including biological role) and then to mechanism. The ‘now classical view that the earmark of a living thing is not the chemical composition of its parts but their organization’ (attributed to Claude Bernard by Dubois, 2007) was not available to Darwin but is a pillar in the version of evolution theory applicable to One Health.

Theories in the sense applying to the practice of science provide explanations and predictions within the realm of biology. Three in particular (the cell theory, the germ theory of disease and the theory of evolution by natural selection) are indispensable to the science that underpins the broad veterinary agenda from primary care of animals, to participation in One Health, and the scope of veterinary services as described by the World Organisation for Animal Health (OIE, 2015). Strict

[24]‘It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us’ (Darwin, 1872).

demarcation between the meanings of laws and theories as used in the practice of science applies to this endeavour for renewing the theory of evolution by natural selection for use in One Health[25].

a. Cell theory

The cell theory identifies the cell as the smallest life form or unit of living matter that is able to function independently and establishes that all living things depend upon cells and can be made up of one or more cells. The phrase ‘all living things depend upon cells’ allows for viruses and prions as life forms, living things or ‘organic beings’. Cells are the basic structural and organisational units of of multicellular organisms, and all cells come from pre-existing cell (see Harris, 1999; Hand, 2019). Cell theory generates the concept of biological organisation (see section 4.3.1) and provides foundations for the disciplines of anatomy, physiology, pathology and ecology.

b. Germ theory of infectious disease

Germ theory recognises that infectious disease can be caused not only by macroscopic metazoan pathogens but also by microscopic moneran (bacterial), protistan (protozoan), fungal and viral pathogens (see Merchant and Packer, 1961; Worboys, 1991). In doing so, the germ theory of disease gave rise to the disciplines of microbiology and virology and the word ‘germ’ subsequently became a synonym for any infectious agent. Definitions of the word ‘germ’ that operated in the nineteenth century (see Box 1) facilitated the hypotheses leading to the identification of microbial pathogens and the establishment of the germ theory as a means for explaining a vast body of evidence and an indispensable tool for effective action against infectious diseases.

The essence of the word germ that engendered the germ theory of disease is ‘that portion of an organic being [cellular or sub-cellular life form] which is capable of development into the likeness of that from which it sprang: a rudiment of a new organism’ (Oxford English Dictionary, 1933)[26]. Note that the word germ covers metazoan endoparasites and ectoparasites and diseases caused by these agents qualify unreservedly as infectious as manifested within standard medical texts (Benenson, 1995; Bennett et al, 2020; Braunwald et al, 1987), a history of transmissible animal diseases (Blancou, 2000), and the fact sheets of the World Health Organisation (https://www.who.int/news-room/fact-sheets). Metazoan parasites both infect in the sense of invading tissues and organs and infest in the sense of being present in large numbers. The notion that metazoan parasites infest but do not infect (Hoerr and Osol, 1956) is no longer tenable.

Incidentally, the word ‘germen’ also operated in the nineteenth century as a synonym for ‘germ’. Charles Darwin (1876) employed ‘germen’ rather than ‘germ’ in this manner. The word ‘germ’ in germ plasm (Weismann, 1893) is explainable according to the definitions in Box 1.

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[25] Despite what has been presented clearly in two reports from the US National Academies of Science (NRC, 2008; NAS, 2009), what is said in *Origin of Species* and the Oxford English Dictionary, and what is set out in dictionaries of science, the words ‘theory’ and ‘law’ are still used erroneously in peer-reviewed publications (q.v. Crouch and Bodmer, 2024).

[26] https://archive.org/details/in.ernet.dli.2015.147246/page/n785/mode/2up

Box 1: Definitions of the words ‘germ’ from Webster’s Dictionary (1844), the Oxford English Dictionary, First Edition (1888-1933) and Chambers’s Dictionary (1867): see references below.

<u>Webster’s</u>

Seed; spore of a plant; element that can develop in the likeness of the form from which it sprang.
Origin; source from which anything springs.

<u>OED</u>

1. That portion of an organic being [life form] which is capable of development into the likeness of that from which it sprang: a rudiment of a new organism.
2. a. In the Linnaean nomenclature: the ovary *obs.* b. the seed *lit* and *fig*.
3. In early use, vaguely the ‘seed’ of a disease. In modern use, a microorganism or microbe; one of the microbes which are believed to cause disease.
4. *fig.* That from which anything springs or may spring; an elementary principle; a rudiment.

<u>Chambers’s</u>

That which is to produce an embryo: in *bot.* The seed bud of a plant; a shoot: that from which anything springs; the origin, a first principle.

Webster, N (1844) *American Dictionary of the English Language* (https://en.wikipedia.org/wiki/Webster%27s_Dictionary).
Murray, JAH (1888-1928) *A New English dictionary on Historical Principles founded mainly on the materials collected by the Philological Society*; Philological Society, London. Oxford Clarendon Press (https://archive.org/details/newenglishdictio04murruoft/page/130/mode/2u).
Donald, J (1867) *Chambers’s Etymological Dictionary of the English Language*. W and R Chambers, London and Edinburgh (https://www.google.com.au/books/edition/Chambers_s_Etymological_Dictionary_of_th/hSRTAAAAcAAJ?hl=en&gbpv=1&printsec=frontcover).

A recurring theme throughout this endeavour is semantic and terminological confusion that may burden global English as the current vehicular language of science. The words infectious, communicable, contagious and transmissible as they apply to disease and the germ theory can be confusing. Put simply, these words cover the same set of issues in host-pathogen interactions but may emphasise different aspects of these issues.

A pathogen is a living agent capable of producing disease (Hoerr and Osol, 1956). To be successful, a pathogen requires capabilities for (1) entry into a host via portals of entry, (2) establishing residence in the host including dissemination to specific sites, successful competition with indigenous microbes, the acquisition of nutrients, the avoidance or circumvention of the host’s innate or adaptive immune responses, (3) replication in the host and then (4) dissemination to portals of exit to become sources of spread or contagion to new susceptible hosts (Osterholm and Hedberg, 2015).

The words infect, infection and infectious embrace all capabilities described for pathogens. Infection refers to the process of implanting an infectious disease agent into the body of a host, the presence of an infectious disease agent in the body of a host, the association between an infectious disease agent and a host and, lastly, the communication or transmission of a disease from one subject to another. Infectious disease agents include biological entities (germs) such as prions, viruses, bacteria (monerans), protozoa (protistans), fungi and metazoan endoparasites and

ectoparasites. Characteristics of the portals of exit and entry determine infectiousness along with the agent's ability to survive away from the host (Osterholm and Hedberg, 2015). Infectivity refers to the characteristics of a pathogen that allow it to enter, survive, and multiply in a host.

The word communicable emphasises the first and fourth set of capabilities described above for pathogens. These are (1) the capability for entry into a host via portals of entry and (4) the passage through portals of exit to become sources of spread or contagion to new susceptible hosts. The word transmissible can sometimes troubled by a particular shade of meaning that comes from the Henle-Koch postulates which highlight the necessity for experimental transmission for establishing a living agent as the cause of disease. However, prions were identified as disease agents or germs (as described in Box 1) through their association with the transmissible spongiform encephalopathies (TSEs) and demonstrations of their transmissibility by laboratory studies (Hörnlimann et al, 2007; Hörnlimann, 2007; Prusiner, 2007). Controlled field studies demonstrate that scrapie in sheep and chronic wasting disease in deer transmit both prenatally and postnatally in the field (Greenlee, 2019; Williams, 2005).

The words contagious and contagion run in parallel with the words transmissible and communicable. Contagion is process by which a disease agent is passed from one person or animal to another by direct or indirect contact or by way of an intermediary. Direct contact can be via excreta or other discharges from the body. Indirect contact can be via the disease agent in water or air substances or on inanimate objects (fomites). A contagious disease is one that spreads by means of the process of contagion.

For purpose of uniting germ theory and evolution theory for action in One Health, infectious diseases are those caused by pathogens (e.g. viruses, prions bacteria, fungi and metazoan parasites) but do not necessarily pass from one host to another. For example, tetanus is the result of infection but is restricted to the host. Communicable diseases are infectious diseases that can be spread from one host to another by direct contact, airborne droplets, body fluids, or vectors. Transmissible diseases cover a broader scope than communicable diseases and include the zoonotic infectious diseases that transfer between multiple host species.

c. The theory of evolution by natural selection

The theory of evolution by natural selection (Darwin; 1858, 1859 and 1872: Wallace, 1858 and 1889) cuts across all biological disciplines and has been heralded as 'outstandingly the most important theory in biology', 'a beautifully simple and easily understood idea' and 'the only theory that can seriously claim to unify biology' (Ridley, 2004) and the main unifying idea in biology (Maynard Smith, 1993). Bowler (1989) draws attention to the societal impacts of the theory of evolution by natural selection by saying that 'the "Darwinian revolution" has always ranked alongside the "Copernican revolution" as one of those episodes in which a new scientific theory symbolizes a wholesale change in cultural values'. In actuality, the theory of evolution by natural selection (theory of evolution by natural selection) as applied to life is logically subordinate to and dependent upon the cell theory because cells form the fabric upon which evolution acts. The

aphorism *omnis cellula e cellula* (Virchow, 1858; see Porter, 1997) extends to unreservedly to evolution but was not within Darwin’s world view. Furthermore, Darwin’s phrase ‘conditions of life’ requires covers factors explained by cell theory. Cell theory, germ theory and theory of evolution by natural selection can be proposed as an interdependent and harmonised trio for enlightening One Health (see section 4.1.1 and Figure 2).

No one theory has precedence and the united trio of cell theory, germ theory and evolution theories supports the whole of biology and its practical applications in the same manner as atomic theory supports the whole of chemistry. Theories as per the National Academies of Science of the USA are an indispensable tool for understanding the body of knowledge in a given discipline and this understanding can channel knowledge into practical application. The theory of evolution by natural selection (theory of evolution by natural selection) is not a law and erroneously naming it as a law (Dodson, 1976; Fields and Johnston, 2010; Crouch and Bodmer, 2024) is an impediment to its practical application. The renewal of the theory of evolution by natural selection for use in One Health demands disciplined use of polysemous terms like ‘theory’, ‘theoretical’, ‘nature’ and ‘natural’ and the development of precising definitions for all its components.

The so-called modern synthesis of evolution (succinctly explained and placed in historical context by Smocovits, 2018; see Box 2) has not readily catered for matters such as niche construction, epigenetic inheritance, neoplasia, symbiogenesis, lateral or horizontal transfer of mobile genetic material such as DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) and the actions of mobile genetic elements[27] containing DNA and RNA, dynamic changes in viruses, infectious disease emergence and the prion phenomenon. Accordingly, there have been calls for what has been termed an extended evolutionary synthesis (Gould, 2002; Laland et al., 2014 and 2015; Müller, 2017; Noble, 2015; Pigliucci, 2009), or an inclusive biological synthesis (Corning, 2020). The extended evolutionary synthesis refers to 'an adjusted evolutionary framework that adequately synthesizes the multitude of new theoretical elements' (Müller, 2017) or a paradigm shift (Pigliucci, 2009) to make the theory of evolution by natural selection compatible with new phenomena.

Box 2: The Modern Synthesis (Smocovitis, 2018)

[27]Mobile genetic elements include plasmids, transposons, integrons, introns and viral agents (Wikipedia).

The ‘modern synthesis’ generally refers to the early to mid-century formulation of evolutionary theory that reconciled classical Darwinian selection theory with a newer population-oriented view of Mendelian genetics that attempted to explain the origin of biological diversity. It draws on the title of zoologist Julian S. Huxley’s book of 1943 titled *Evolution: The Modern Synthesis*, a semi-popular account of evolution that ushered in this ‘modern’ synthetic view of evolution. Covering an interval of time approximately between 1920–1950, it also refers to developments in understanding evolution that drew on a range of disciplines that were synthesized or brought to consensus that generally include systematics, paleontology, and botany with a populational view of evolutionary genetics. Whether or not it served to unify the study of evolution, or to unify the disparate biological sciences—and whether or not it led to the emergence of a science of evolutionary biology, as some of its proponents have claimed—remains a topic for discussion.

A website, the Third Way of Evolution (www.thethirdwayofevolution.com), provides a forum for reconciling the theory of evolution by natural selection with newer biological knowledge. The adjusted evolutionary framework labelled as either the extended evolutionary synthesis or the inclusive biological synthesis builds from ‘descent with modification’ and is foreshadowed by the theory of evolution by natural selection as advanced by Darwin in all editions of *Origin of Species* from 1859 to 1872. The view of natural selection as a simple passive filter (Noble, 2021) can strip away much of the semantic baggage around the term ‘natural selection’ (see section 2.5.3). Fitzgerald and Rosenberg (2019) point out discrepancies between the modern synthesis and current knowledge of mutation and its mechanisms. Baverstock (2021) and Goldman and Landweber (2016) give a contemporary view of genes and genomes that call for a reworking of natural selection theory. The COVID-19 pandemic highlights clarity around the evolution of viruses as a pressing concern. This demands a broad perspective and progression from the previous modern synthesis or neodarwinism to a version of the theory of evolution by natural selection made possible by the digital revolution and the information age, which was consolidated in the last part of the twentieth century (Coggan, 2020).

Futuyma and Kirkpatrick (2017) sum up evolution as fact and theory in the following way that suits the proposed ontology: 'The theory of evolution is a body of interconnected statements about natural selection and the other processes that are thought to cause evolution, just as the atomic theory of chemistry and the Newtonian theory of mechanics are bodies of statements that describe causes of chemical and physical phenomena'. In consequence, the present task is to construct a comprehensive and consolidated account of the body of interconnected statements that constitutes the theory of evolution by natural selection and to make it as clear-cut and operable as cell theory and the germ theory of disease. The task is facilitated by recognising the theories in science can be expanded in detail according to new knowledge (see section 3.1).

2.5 A perspective from communication: universal intelligibility and universal access to knowledge

Communication, which is the exchange of information, impels One Health. The goal is reliable information made universally intelligible and accessible through means and modes of exchange that are fit for purpose. These means and modes of exchange have two components. The first is

language, and its systematic study within linguistics. The second component concerns the resources and repositories of information and knowledge and their accessibility. As to the first component, language has several meanings relevant to One Health. Language can refer to (1) systems of communication with or without words, (2) specialist vocabularies such as those used in the various disciplines of science, and the speech of a country, region, or group of people, including its diction, syntax and grammar. Linguistics is the systematic study of language and covers the meaning of words (semantics), the meanings of words in particular context (pragmatics). sentence structure (syntax) and sound patterns in language (phonology). As to the second component, the resources and repositories of information and knowledge include books and journals, libraries, bibliographies, and bibliographic indexes available in print or electronic form. Access to knowledge has been transformed by the Internet.

Language barriers and information management are vitally important to the outreach of international bodies like the WHO, the FAO, the WOAH, the OECD and the World Bank. All these bodies have multiple official languages and multilingual websites. FAO and WHO have regional offices. Official languages include include English, French, Spanish, Arabic, Chinese, and Russian. FAO has a program called the Agricultural Information Management System (AIMS) that seeks to improve universal access to the knowledge and information that benefits food production and security (see https://aims.fao.org/). AIMS is linked to FAO's AGROVOC, which is a multilingual controlled vocabulary based on computer science that can collate and arrange knowledge for subsequent sharing (see https://www.fao.org/agrovoc/home).

2.5.1 World English as a vehicular, lingua franca or common or bridge language for science

The depictions of language and communication given in the introduction to this section come from the *Encarta Dictionary of World English* (1999). In this connection, the English language has merged British and Irish English, American English and six other varieties of English to become Global English, International English or World English. The result is a global resource, not a linguistic hegemony, and is the English referred to throughout the present document. McArthur (1999) states that World or Global English 'does not owe its existence – or its future – to any nation, group, or individual', 'is the possession of every individual and community that wishes to use it, wherever they are in the world' and that 'it is in effect as democratic and universal an institution as mankind has ever possessed'. World English blossomed in the 1990s along with the thrust towards globalisation and increasing recognition that world cultures and economies are connected, interdependent and sources of mutual benefit.

Language, in one of its meanings, refers to a system of spoken and written communication used by a particular country or community. The workforce in One Health constitutes a global community and One Health seeks to benefit the whole world. Article 27 of the Universal Declaration of Human Rights (United Nations, 1948) states that 'everyone has the right freely to participate in the cultural

life of the community, to enjoy the arts and to share in scientific advancement and its benefits’. Accordingly, it is imperative that works of science written in one language can be translated with fidelity into any other language. The issue here is not the English language, nor any of the other languages that have dominated in science. Sixteen other languages have been listed as dominant in science over time and place: Arabic, Chinese, Danish, Dutch, French, German, ancient Greek, Italian, Japanese, Latin, Persian, Russian, Sanskrit, Swedish, Syriac, and Ottoman Turkish (Gordin, 2015). Lack of clarity and confusion can occur within all languages and can obstruct the common understanding required for global implementation of One Health.

World English succeeded from German, French, Latin and Greek as the vehicular, bridge or common language of science that can disseminate working concepts such as ‘cell’, ‘metabolism’, ‘atom’ and ‘molecule’, tools such as the Système International (d'Unités) and global naming systems used in disciplines such as biology and geology, and science as the body of knowledge that belongs to humanity (Hohenberg, 2010). This succession from earlier dominant vehicular languages to English has been chronicled by (Gordin, 2015). Globalisation, the process by which social institutions are adopted on a global scale, has been a driver of change and has been assisted by the appearance of academic databases and search engines on the Internet. These processes of change continue and the notion of multiple vehicular languages for science has come into play.

The concept of a single vehicular language for science such as World English is a convenience but does not rule out other possibilities. Less than 15% of the world’s population speak English (https://www.ethnologue.com/). Accordingly, recognising and alleviating the difficulties faced by nonnative speakers of English is a necessary step towards an inclusive global community of scientists and universal accessibility to scientific knowledge and its benefits. Hence, the FAO initiatives of AIMS and AGROVOC (see previous section) and the proposed ontology that can make evolution theory universally accessible and actionable. An editorial by Drubin and Kellogg (2012) looks to the impact of these language issues on publishing research results and discusses how researchers, manuscript reviewers, and journal editors can help towards equity in international scientific communication. Linguistic diversity in science is being pursued as part of the open science initiative and has been given impetus by the Helsinki Initiative on Multilingualism in Scholarly Communication (2019) with support from UNESCO (2022) and the Council of the European Union (2022). The key issue is that any vehicular language must be purged of vernacular hindrances to enable effective communication between people with different native languages, Some native languages may not be able to accommodate the clear communication of science.

Three aspects of communication bear upon how the theory of evolution by natural selection can be renewed to serve One Health. The first concerns semantics or the meaning of words, which is dealt with in section 2.5.2. The second arises from experience with the COVID 19 and relates to concerns about an epidemic of misinformation (West and Bergstrom, 2021)(see section 2.5.5). The third aspect concerns harms that may arise from English (or any other language) as the vehicular language of science. These harms can be listed as inequities regarding access to resources of

information and knowledge, restricted opportunities for publishing in the scientific literature (see Amano et al., 2023) and possible narrowing of vision and diversity of thought.

A primary issue here concerns the hierarchical relationship between communication as a super-ordinate concept and language as a subordinate concept and how an understanding of this relationship can expedite the renewal of evolution theory for the purposes of One Health. Communication encompasses all means for exchanging information, ideas, and feelings between and among life forms or machines, and can occur through speech, words and writing, various sensory means (sound, sight, touch), feedback and feed-forward loops, and electronically transmitted codes. Communication in biology refers to the signalling of information from one organism to another, usually with the intention of altering the recipient's behaviour and is a factor in all biological associations. Signals used in communication may be visual (such as the human smile or the display of colourful plumage in birds), auditory (for example, the whines and barking of a dog), olfactory (such as the odours released by the scent glands of a deer), electrical (such as the pulses emitted by electric fish) or tactile (such as the nuzzling of male and female elephants) (Lafferty and Rowe, 1995).

The super-ordinate category of communication encompasses language, music (Cross, 2014), diagrams, mathematics, and the ontologies used in information technology. Language provides a system for communicating ideas and feeling through a combination signs, sounds, gestures, and marks with particular meanings. Diagrams use visual symbols to communicate information, ideas, or relationships in order to make complex concepts easier to understand. Diagrams complement language and enhance comprehension. Mathematics communicate precise and unambiguous information about quantities, structures, and their relationships and provide a means for understanding the physical world. Ontologies facilitate communication within information technology by representing knowledge as a set of concepts and relationships that exist among those concepts (Neapolitan and Jiang, 2018). Ontologies allow for interoperability and information sharing.

A final word is that the proposed ontology for evolution theory provides a communication means for implementing the worldwide application of evolution theory in One Health and realising its value in managing hazards such as infectious disease and threats to food security and environmental stability. The proposed ontology together with its set of precising definitions seeks to be a concise, comprehensive and contemporary account of evolution theory that can bypass the often arcane, encumbered and perplexing body of earlier literature around evolution that was dominated by the English language, often in insular forms that preceded World English. Specific details in the proposed ontology are open to the organised scepticism that empowers science (Merton, 1942) and to subsequent modification. The proposed ontology and its accompanying precising definitions expressed in World English can be translated into any chosen language and can guide other transactions around evolutionary biology in that chosen language. In doing so, it can support the reliability of those transactions and reduce the need for large scale translations from the English language.

2.5.2 Semantic and terminological confusion within evolutionary biology

Problems with semantics and terminological confusion are actualities within evolutionary biology and a quote from Feynman (1988) is relevant to universal intelligibility: 'I learned very early the difference between knowing the name of something and knowing something'. The names of things, however, are crucial because they allow for communication that advances knowledge and a major theme of the present work is that multiple meanings of words can impair and have indeed impaired a clear understanding of the theory of evolution by natural selection. Foremost are the words theory, nature and natural which have particular meanings that can direct the renewal of the theory of evolution by natural selection and eliminate past obfuscations and encumbrances. Figurative language is another matter that can impede universal intelligibility. Darwin was obliged to use figurative language like 'struggle for existence' or 'struggle for life' because he was limited by the scientific vocabulary and knowledge available to him and perhaps because he avoided words that could derail argument. Figurative language[28] persists as a detrimental and obfuscating factor for evolutionary biology. The present task of renewing the theory of evolution by natural selection for One Health will emphasis literal language and relegate figurative language. Explicit attention to possible ambiguities in words like 'theory' and 'nature' and a concentration on literal rather than figurative language can achieve the communication ideal of 'many languages, one voice'.

Laland and Brown (2002) recognise that the theory of evolution by natural selection applied to human behaviour and society has become a 'minefield of terms and concepts'. In consequence, they have set out a 'guide for the perplexed', which refers to those 'who have struggled to understand the plethora of confused terms and apparent differences of opinion and approach in the use of evolutionary theory to study human behaviour'. Their 'guide for the perplexed' may facilitate the universal intelligibility of natural selection theory.

A prime example of confused terminology concerns the slanted version of the theory of evolution by natural selection that rationalised Social Darwinism and allowed perverse application of the phrase 'survival of the fittest' within social discourse. This phrase appears in the fifth and sixth editions of *Origin of Species* (1869 and 1876). It was coined by Herbert Spencer (1820-1903) and recommended to Darwin by Alfred Russel Wallace. In his book, *The Factors of Organic Evolution*, Spencer (1887) describes 'survival of the fittest' as a metaphor connecting natural selection with what was called the 'vital activities' of organisms or what Darwin called the 'success in the struggle for life'. Spencer (1898) refers again to 'vital activities' and 'vitality' in his book, *The Principles of Biology.* 'Vital activities' are the organismal functions that allow for life and which form the subject matter of physiology. 'Survival of the fittest' will be re-expressed according to physiology and will inform the proposed ontology for the theory of evolution by natural selection. Superlatives like 'fittest' have a potential to confuse rather than clarify and can compromise clear communication in or about science.

[28]In literal language, words have their normal meanings as set out in dictionaries. Figurative language extends the meaning of words beyond their normal sense and includes figures of speech such as similes, metaphors, hyperbole, and personification (Vivian and Jackson, 1961).

Laland and Brown (2002) also shed a light on controversies around notions such as group selection, kin selection, reciprocal altruism, and evolutionary game theory. In doing so, they remind that controversy and discord has often occurred in transactions around evolution. This history of discord need not divert from fulsome engagement with the literature on human biology that is available to One Health.

Keller and Lloyd (1992) provide a collection of essays that seek to 'identify and explicate those terms in evolutionary biology that, though commonly used, are plagued in their usage by multiple concurrent and historically varying meanings'. A factor contributing to confusion is the many debates and controversies on what is termed philosophical issues[29] connected with evolution; for example, that around the word 'progress' (see Coyne, 1997; Shanahan, 2000; Mayr, 2001), which can have the distinct teleological and deterministic meaning of improvement whereby evolution proceeds toward some externally defined goal (Mayer, 2014).

The extensive list of terms of seen as troubled by polysemy, ambiguity, and uncertainty (Keller and Lloyd, 1992) is shown in Table 3. With the exception of the Chapter on neutralism (Kimura, 1992), all essays in the collection come from the anglophone world where the English used was plagued by 'multiple concurrent and historically varying meanings'. These defects in language are an obstruction to a universal understanding of evolutionary biology and an impediment to its full implementation within One Health. A full appreciation of possible detriments to intelligibility can direct actions to facilitate communication and allow faithful translations from World English to other languages, from other languages to World English, and between other languages. The fundamental issue is not World English itself but the sources and causes of intelligibility that can beset any language.

Table 3: Terms in evolutionary biology troubled by 'multiple concurrent and historically varying meanings'.

1. Adaptation	11. Extinction	21. Individual**	31. Progress
2. Altruism	12. Fitness*	22. Lamarckism)	31. Random drift
3. Character	13. Gene	23. Macromutation	32. Resource
4. Community	14. Genetic load	24. Monophyly	33. Sexual selection
5. Competition	15. Genotype and phenotype	25. Mutualism and cooperation	
6. Darwinism	16. Group selection	26. Natural selection	
7. Environment	17. Heritability	27. Neutralism	
8. Epistasis	18. Heterochrony	28. Niche	
9. Eugenics	19. Heterosis	29. Parsimony	
10. Evolution	20. Homology	30. Phenotypic plasticity	

[29]The phrase 'philosophical issues' covers a broad scope. The debates in question appear to have concerned metaphysical and ontological aspects of evolution rather than 'natural philosophy' which now refers to science, where matters can be ground-proofed by actual observations in the real world.

*The precising definition of fitness used for the proposed ontology is set out in the glossary and derives from an exploration in section 3.3.4. Barker (2009) describes how the term ‘fitness’ has been applied different ways and with different definitions within the quantitative genetics applied to livestock breeding.
**It is possible that a common view of Lamarckism as the inheritance of somatic characteristics acquired by an organism during its lifetime is a flawed interpretation of what Lamarck actually explicated in his book *Philosophie Zoologique* (1809). This matter has been a possible diversion and merits resolution by scrutinising the text of this book in its original French and its subsequent English and German translations.

The terms ‘trade-off’ and ‘arms race’ classify as figurative language. They were coined in the 1980s to package aspects of coevolution to a particular audience and can be distracting to other audiences. ‘Trade off’ and ‘arms race’ have now been adequately defined (Buckingham and Ashby, 2022; Ebert, 2014; Stearns, 2014; Turner, 2014) and are not included in the list of troubled terms in evolutionary biology. Turner (2014) points out that ‘we are locked into a coevolutionary arms race with pathogens’. Ebert (2014) points to the value of trade-offs for understanding the evolution of virulence in pathogens. Turner (2014) describes coevolutionary arms races as the ‘sequence of mutual counter adaptations of two coevolving species, such as a parasite and its host’ and trade-offs as ‘a balancing between two traits that occurs when an increase in fitness (survival and reproduction) due to one trait is opposed by a decrease in fitness due to a concomitant change in the second trait’.

More recently, Noble (2021) has drawn attention to deficiencies in the language (the English language) used for biology in the second half of the twentieth century and repercussions for cogency of the so-called Modern Synthesis of the theory of evolution by natural selection. Noble (2021) proposes that the resulting misinterpretations of what molecular biology may have shown can be addressed through 'a multi-level organisation view of biology’. Organisation as a fundamental concept of biology and a necessary component of the theory of evolution by natural selection is dealt with in section 4.3.1. In like vein, Buckingham and Ashby (2022) outline possible refinements to the mathematical models that could make the concepts of arms races and trade-offs more amenable to application within One Health, which is locked into a coevolutionary arms race with pathogens (Turner, 2014). The concepts of trade-offs and the coevolutionary arms race hinge on reciprocal coevolution and can thus be bundled with niche construction (see section 4.3.3) for consideration within One Health.

2.5.3 Disordered concept hierarchies as material fallacies within evolutionary biology

Some of the confused and perplexing terminology in evolutionary biology may have an origin in defective concept hierarchies. Defective concept hierarchies classify as material fallacies (Fearnside and Holther, 1959). Concept hierarchies are described in works on cognitive psychology (Goldstein, 2011) and information technology (Negnevitsky, 2005; Russell and Norvig, 2010), where they form the basis of ‘knowledge engineering’ and ‘knowledge representation’. An explicit and intelligible concept hierarchy will be instrumental in composing the proposed ontology for facilitating a universal understanding of natural selection theory.

The following account of concept hierarchies is framed around particular meanings of (1) concept and category and (2) superordinate and subordinate concepts or categories. Meanings for 'concept' and 'category' that fit present purposes come from the field of cognitive psychology (Goldstein, 2011). A 'concept' is seen as ‘a mental representation used for a variety of cognitive functions, including memory, reasoning, and using and understanding language; for example, the way a person mentally represents “cat” or “house”’. Category refers to groups of objects that belong together because they belong to the same class of objects, such as ‘houses', 'furniture',” or ‘schools'. Put simply, concepts are the fundamental units or building blocks for perceiving and thinking and categories are groups or sets of things, beings and so on that have common characteristics.

Concepts can be arranged according to categories within hierarchical models or systems, which are described by Goldstein (2011). A hierarchical model or network model of knowledge representation 'consists of levels arranged arranged so that more specific concepts, like canary or salmon, are at the bottom and more general concepts, such as bird, fish, or animal, are at higher levels'. A hierarchical system refers to the organisation of categories where 'larger, more general categories are divided into smaller, more specific categories', which 'can, in turn, be divided into even more specific categories to create a number of levels are divided into smaller, more specific categories'. Levels within hierarchies, from high to low, are termed superordinate, basic or subordinate. Similar hierarchical arrangements are found in the field of linguistics where the term 'hypernym' applies to words with a broad general meaning and 'hyponym' applies to words with a relatively narrower meaning.

2.5.4 Clarity of communication within processes for science-based public policy

Other aspects of linguistics and clarity of communication relate to (1) risk analysis and other means for feeding science into public policy and (2) the example of intelligibility provided by the so-called policy briefing note. Risk analysis is an ordered process for providing the intelligence and foresight necessary for reasoned prevention and remedial actions in One Health and the basics are outlined in FAO’s classic *Manual on the Preparation of National Animal Disease Emergency Preparedness Plans* (Geering et al., 1999). Risk analyses must take stock of uncertainties around (1) variability, which refers to naturally occurring and unpredictable changes, (2) incertitude, which refers to gaps in knowledge, and (3) linguistics where uncertainty comes from words having variable or imprecise meanings (Carey and Burgman, 2008). Linguistic uncertainty extends to ambiguity, vagueness, under-specificity (where parameters or variable are inadequately defined), and context dependence (where time, place and population are inadequately defined). The challenge of universal intelligibility must be met if evolutionary biology is to realise its full promise for One Health. Risk analysis as a means for feeding science into public policy is revisited in the next section and in section 6, where the ramifications of a renewed version of the theory of evolution by natural selection are explored.

The format of briefing notes used for policy processes in public and private institutions is designed to distil complex information intelligibly and accurately and is exemplified by the briefing note series used in FAO's program for Integrating Agriculture in National Adaptation Plans[30]. This format could be used mediate faithful translation of scientific knowledge between World English and other languages and thus to facilitate interoperability within One Health. Briefing notes often consist of a series of headings and accompanying dot-points and dash-points to convey a concise and coherent synopsis of a subject. This particular version of a briefing note will be reflected in parts of section 4.2 to summarise the central elements of biology that make sense of evolution and will be applied to the ontology for the theory of evolution by natural selection in section 5.

2.5.5 The hazard of misinformation

Misinformation[31], disinformation, untruths, quackery (pretence of knowledge and skills) and so-called junk science have been a perennial hazard for One Health. Their potential for harm is said to have reached 'crisis proportions' (West and Bergstrom, 2021) and this is important background for the proposed user interface between the theory of evolution by natural selection and One Health. West and Bergstrom (2021) report that misinformation threatens international peace, democratic decision-making, public health and the well-being of the planet. Misinformation has undermined control and management of COVID-19 pandemic and has prompted the World Health Organization's declaration of an 'infodemic' (Zaracostas, 2020). West and Bergstrom (2021) state that 'scientific communication has fallen victim to the ill effects of an attention economy' and go on to say that science is not broken but functions remarkably well despite the challenges and 'remains the greatest of human inventions for understanding our world'.

Evolutionary biology has been troubled by misinformation fuelled by social movements such as eugenics and social Darwinism and by the naturalistic fallacy which has been employed to rationalise malign human behaviour and immorality. According to Hull (2002c): 'The naturalistic fallacy with respect to morality is reasoning from what *is* the case to what *ought* to be the case. For example, in all societies throughout the history of the human species, men have held most of the power. To conclude from that fact that such patriarchal societies are morally preferable to matriarchal societies, or to societies in which males and female share power equally, is an instance of the naturalistic fallacy.' In *The Descent of Man and Selection in Relation to Sex* (1874), Darwin rules out the naturalistic fallacy by stating that 'any animal whatever, endowed with well-marked social instincts, the parental and filial affections being here included, would inevitably acquire a moral sense or conscience, as soon as its intellectual powers had become as well, or as nearly as well developed, as in man.'

[30] http://www.fao.org/in-action/naps/news-events/detail/en/c/1127468/ - accessed February 9, 2021

[31] The semantic field that covers 'misinformation' in the Macquarie Thesaurus positions this word as a euphemism for 'lie' or 'untruth'. FAKERY 240.3 contains the following words: lie, alias, canard, distortion, equivocation, evasion, exaggeration, fable, fabrication, factoid, fairytale, falsehood, fib, fiction, half-truth, invention, legal fiction, misinformation, misreport, misrepresentation, misstatement, perjury, pretext, prevarication, story, tale, taradiddle, untruth, white lie, whopper.

2.6 A perspective from the translation and extension of knowledge and skills

There are many descriptions of the notion of translation as it applies to medicine and the notion of of extension as it applies to agriculture. The gist of both is captured in an aphorism from Johann Goethe (1749-1832): ‘Knowing is not enough; we must apply. Willing is not enough; we must do’. In public health, translation aims at implementing sound processes for disease treatment and prevention and the promotion of good health. In agriculture, extension aims at putting knowledge into practice, thereby benefiting society as a whole. According to Oakley and Garforth (1985) ‘extension is a term which is open to a wide variety of interpretations…. a dynamic concept in the sense that the interpretation of it is always changing’. Put simply, translation and extension are processes for putting knowledge to definite effect. Both notions are empowered by the sharing of knowledge and the mutual recognition of skill, and both attest to the ideals of education and knowledge societies (UNESCO, 2005). The observations, experience and tacit knowledge of animal carers, agriculturalists and others open the way to new explicit knowledge according to what Ritchie-Calder (2007) describes as a synergism between the know-how of technology and the know-why of academic science.

Greenhalgh and Wieringa (2011) argue that the concept of knowledge translation was basically a ‘good thing’ in the practice but that the conceptualisation of knowledge should be broadened. This notion was taken up and embellished in an associated editorial by Abbasi (2011) who stated that facts are only one dimension of knowledge. Abbasi referred to the philosopher Aristotle (384 BCE - 322 BCE) who described knowledge as being composed of facts (episteme), skill (techne), and practical wisdom (phronesis). Abbasi went on to say that:

> 'Facts need to be placed in context – which requires tacit awareness – interpreted, and linked to further questions With this broader definition of knowledge, medicine is neither a science nor an art. It is an uncertain, paradox-laden, judgement-dependent, science-using, technology-supported practice’.

One Health is likewise an uncertain, paradox-laden, judgement-dependent, science-using, technology-supported practice that should not be impeded by narrow literalism. The theory of evolution by natural selection has a potential for augmenting the phronesis that applies in One Health and the pursuit of global health. The term phronesis highlights the critical thinking and clinical reasoning that has guided the development and sound application of medicine throughout history (Kassirer et al, 2010) and which can apply across One Health.

2.7 Risk analysis and hazard characterisation

Risk analysis and particularly its risk assessment step which includes hazard characterisation presents as an indispensable and perhaps underutilised methodology for applying evolutionary biology within One Health. The following excerpt from the Foreword to FAO (2013a), *World*

Livestock 2013 Changing disease landscapes, captures the pre-eminent value of the risk assessment:

> 'The publication suggests the need for a paradigm shift in risk assessment, with more attention to a health-in-development approach that engages society at large and is built on analysis of the drivers of disease dynamics. such analysis will be instrumental in defining preventive measures for countering disease emergence, spread and persistence. Four distinct drivers of disease complexes need to be addressed: poverty-related endemic disease burdens in humans and livestock; biological threats and biosafety challenges posed by globalization and climate change; food and agriculture-related veterinary public health threats; and the risk of disease agents jumping species from wildlife to livestock and humans'.

The word 'risk' can mean various things (Hansson, 2011) and provides a classic example of polysemy, or words with multiple meanings that can disrupt clear communication. One stream of meanings comes from the field of financial economics where risk refers to variability of the returns on an investment (Samuelson and Nordhaus, 2010). This stream includes the label ‘risk-based approach’, which refers to certain ideas that assist in the management of organisations. However, the stream of meanings relevant to activities in One Health comes from notions of risk promulgated by the World Organisation for Animal Health (OIE)(2019), the Codex Alimentarius Commission (CAC)(2015) and FAO (1997). The point of risk analysis for these bodies is to design preparedness, prevention and mitigation strategies against hazards or sources of harm. Because confusion can occur, it is emphasised that risk analysis here differs from actuarial and financial risk analysis where statistics are used to estimate probabilities around insurance premiums, life expectancy and so on. Both types of risk analysis are required for One Health.

Explanations of risk analysis and its components from the World Organisation for Animal Health or OIE (2019) can apply throughout One Health. Risk analysis refers to a process composed of hazard identification, risk assessment, risk management and risk communication. Risk assessment refers to the evaluation of the likelihood and the biological and economic consequences of entry, establishment and spread of a hazard. Risk management means the process of identifying, selecting and implementing measures that can be applied to reduce the level of risk. Risk itself refers to the likelihood of the occurrence and the likely magnitude of the biological and economic consequences of an adverse event or effect to animal or human health.

A meaning of ‘hazard’ suitable for present purposes and One Health can build upon the definition provided by the World Organisation for Animal Health. A hazard is a biological, chemical or physical agent in, or conditions or circumstance in people, animals, animal products or the environment with the potential to harm the health and wellbeing of people, animals or ecosystems. The words ‘conditions or circumstances’ and ‘the environment’ allow for evaluating the hazards that arise through evolutionary processes. Situations which allow coronaviruses from different species of host to mingle and generate new pathogenic variants provide a topical example of an evolutionary hazard and highlight the potential benefits of a more deliberate application of evolutionary biology in One Health. In such circumstances, the theory of evolution by natural selection becomes a vital component of protocols for hazard identification and hazard

characterisation. As a consequence, the theory of evolution by natural selection will be indispensable to the ‘paradigm shift in risk assessment’ recommended for tracking the drivers of disease emergence, spread and persistence and providing knowledge for the design and execution of countermeasures (FAO, 2013a).

2.8 Reciprocity and knowledge sharing within and between One Health and the field of evolutionary biology

Darwin’s 'one long argument' that led to the 'theory of descent with modification through variation and natural selection' is based heavily on the know-how and practices of animal and plant breeders (see Box 3). Darwin’s summation of these selective breeding practices as 'artificial selection' provided an analogy and a starting point for his formulation of ‘natural selection'. In short, agriculture and resources management as components of One Health have a history of contributing essential knowledge to evolutionary biology. This may simply reflect the fact that all biological knowledge has an ultimate foundation in shared observations of nature and that perceived boundaries between science and technology are an illusion. Tyndall (1879) provides an apt quotation from Louis Pasteur: ‘No, a thousand times no! There exists no category of sciences to which the name of applied science could be given. We have science and the applications of science, which are united to each other as the fruit and the tree on which it grew.’ As an aside, John Tyndall outlined the instrumental role of carbon dioxide in global warming during the middle of the nineteenth century and was preceded by Eunice Foote in doing so (Jackson, 2020).

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Box 3: What Darwin said in *Origin of Species* about how animal and plant breeding inspired his formulation of the theory of evolution by natural selection.

From page 4-5: It is, therefore, of the highest importance to gain a clear insight into the means of modification and coadaptation. At the commencement of my observations it seemed to me probable that a careful study of domesticated animals and of cultivated plants would offer the best chance of making out this obscure problem. Nor have I been disappointed; in this and in all other perplexing cases I have invariably found that our knowledge, imperfect though it be, of variation under domestication, afforded the best and safest clue. I may venture to express my conviction of the high value of such studies, although they have been very commonly neglected by naturalists.
From pages 84-85: But I do believe that natural selection will generally act very slowly, only at long intervals of time, and only on a few of the inhabitants of the same region. I further believe that these slow, intermittent results accord well with what geology tells us of the rate and manner at which the inhabitants of the world have changed. Slow though the process of selection may be, if feeble man can do much by artificial selection, I can see no limit to the amount of change, to the beauty and complexity of the coadaptations between all organic beings, one with another and with their physical conditions of life, which may have been effected in the long course of time through nature's power of selection, that is by the survival of the fittest.

From page 410-411: We shall thus see that a large amount of hereditary modification is at least possible; and, what is equally or more important, we shall see how great is the power of man in accumulating by his Selection successive slight variations. But man can and does select the variations given to him by nature, and thus accumulates them in any desired manner. He thus adapts animals

and plants for his own benefit or pleasure. ……..…There is no reason why the principles which have acted so efficiently under domestication should not have acted under nature. In the survival of favoured individuals and races, during the constantly-recurrent Struggle for Existence, we see a powerful and ever-acting form of Selection

The crucial importance of knowledge sharing between One Health to evolutionary biology is illustrated by the case of natural selection which is listed among the terms plagued by semantic confusion (Keller and Lloyd, 1992). Here, Endler (1992) draws the unsatisfactory conclusion that three common restricted meanings of the term ‘natural selection’ have currency. These are described as mortality selection, nonsexual selection, and phenotypic selection. Endler states that these specific definitions have been useful in exploring various aspects of natural selection and evolution but that if one or more of these restricted definitions are used 'one must make absolutely clear which meaning is intended'. This creates an unacceptable situation where esoteric rather than accessible knowledge has ascendancy.

Added to this, textbooks in the field of evolutionary biology tend to define natural selection in terms of outcomes of a process and are not explicit as to the gist of the process itself. The theory of evolution by natural selection cannot be renewed for its usefulness within One Health without a crisp, intelligible and operationally effective account of natural selection. The following quote in a textbook on animal breeding (Bourdon, 2014) is apt: ‘Simply knowing definitions is not equivalent to understanding a subject, but not knowing them is a sure sign that your understanding is less than complete’. The point is that an effective definition or account of something must provide for an easy and comprehensive understanding of that thing.

This matter of intelligibility as regards selection is revisited in section 3.3.3, where the proposition that Darwin’s *Origin of Species* contains a complete grounding for the theory of evolution by natural selection is spelled out. Darwin’s use of knowledge from animal and plant breeding to construct the theory of evolution by natural selection will be repeated in its present reconstruction for One Health. Indeed, animal and plant breeding classify as potent experimental demonstrations of natural selection where the word natural refers to the qualities that constitute a person or thing (see section 3.1).

Chapter 3. Historical Context for a One Health Renewal of Evolution Theory

‘Study the past if you would define the future’ (Confucius, 551- 479 BCE)
‘Those who cannot remember the past are condemned to repeat it’ (George Santayana, 1905)
- from Hays (2024)

What comes second in this ‘one long argument’ or process to renew the theory of evolution by natural selection for present-day efficacy in One Health is a perspective from history and its implications for the product of renewal. History in the sense of ‘how things came to be’ has an indispensable role in diagnosis across One Health where it informs about the primary and secondary causative factors that harm the health and well-being of individuals, populations, communities, ecosystems and the planet. In brief, history is an accounting of facts and events over time that lead to knowledge, understanding and rational action (see Glossary). Scally and Womack (2004) argue that history requires more emphasis in the practice of public health and refer to works by the historians Carr (1984) and Tosh (1987). Carr (1984) proposes a dual function for history, which is ‘to enable men and women to understand the society of the past and to increase their mastery over the present’. Tosh (1987) states that: ‘To know about the past is to know that things have not always been as they are now, and by implication that they need not remain the same in the future’.

History as an accounting of facts and events links to thought experiments, counterfactuals, hind-sighting and retrospection which are used in everyday contemplation. Thought experiments and the like explore hypothetical situations (‘what if’ scenarios) and envisage what could have happened had circumstances been different. Hindsight can inform foresight and foresight analysis guides the Global Futures and Strategic Foresight platform of the International Food Policy Research Institute, which is directed at food security (Brooks and Place, 2019). Prager and Wiebe (2021) also inquire into strategic foresight as a systematic means for exploring plausible future for agriculture and food security and refer to it as learning from the ‘ghosts of agriculture past’.

Lessons from history can energise the renewal of the theory of evolution by natural selection. One such lesson is the legacy of misunderstanding what theories are in the practice of science and how this misunderstanding constitutes a critical flaw in past renditions of the theory of evolution by natural selection. Other lessons derive from the impacts of vague, ambiguous and figurative language and the absence of reference to cell theory and physiology and in past renditions of the theory of evolution by natural selection. Physiology is the branch of biology that aims to understand the mechanisms of living things (the Physiological Society, https://www.physoc.org/) and this understanding pivots on cell theory. Noble and Joyner (2024) state that ‘reintegrating physiological processes back into evolutionary biology’ can allow it to move beyond encumbrances coming from the so-called Modern Synthesis.

The Modern Synthesis refers to a rendition of evolutionary theory in the mid 20th century that attempted to reconcile natural selection as described by Darwin with Mendelian[32] genetics (Smocovits, 2018). According to Smocovits (2018), the Modern Synthesis drew on disciplines of systematics, palaeontology and botany plus a 'populational view of evolutionary genetics' but not physiology. Furthermore, physiology and cell theory are not referenced as drivers of natural selection in the three books that led the modern synthesis (Fisher[33], 1930; Haldane[34], 1932; Huxley[35], 1942). Absence of a perspective from cell theory and physiology in the modern synthesis impeded extension to issues such as niche construction, epigenetic inheritance, neoplasia, symbiogenesis, mobile genetic elements, dynamic changes in viruses, infectious disease emergence and the prion phenomenon.

In consequence, lessons from history endorse cell theory and physiology as the basis for clear definitions of terms in this renewal of the theory of evolution by natural selection. Cell theory and physiology can be augmented graphically by means of an evolutionary triangle or a version of the epidemiological triangle or triad (Bhopal, 2002; Thrusfield, 1986), which shows relationships between organisms or sub-organismal life forms (viruses and prions), their environment and 'descent with modification'; see section 4.1.1. The terms in question include inheritance, reproduction and variation, selection as in natural selection, fitness, adaptation and species. Disputes around them in the literature associated with the Modern Synthesis (see Keller and Lloyd, 1992) and matters such as the 'gene-centric view of evolution'[36], 'adaptationism' [37], 'structuralism'[38]and 'neutralism and selectionism'[39] are outdated but important historically. Factors in evolution such as genes, selection, variability and adaptation have parity and act as an integrated whole. No single factor dominates. The upshot is that physiology and the cell theory coupled with a perspective from causation and causal inference can give these keys terms intelligibility and utility within the proposed ontology for the theory of evolution by natural selection.

3.1 Theories in the practice of science

The definitions of theory stated earlier in section 2.4.2 (Futuyma and Kirkpatrick, 2017; National Academy of Sciences, 1999; National Research Council, 2008) are consistent and align with a statement from Hawking (1988) on what the word theory stands for in the practice of science:

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[32]Mendelian genetics or Mendelian inheritance proposed by Gregor Mendel (1822-1884 CE) refers to the mode of inheritance that operates in sexually reproducing organisms whereby inherited traits occur two alternative forms or alleles and not by a process of blending.

[33]R.A. Fisher b. 1890, d. 1962.

[34]J.B.S. Haldane b. 1892, d. 1964.

[35]J. Huxley b. 1887, d. 1975.

[36]https://en.wikipedia.org/wiki/Gene-centered_view_of_evolution

[37]https://en.wikipedia.org/wiki/Adaptationism

[38]https://en.wikipedia.org/wiki/Structuralism_(biology)

[39]https://en.wikipedia.org/wiki/Neutral_theory_of_molecular_evolution

> ‘A theory is a good theory if it satisfies two requirements. It must accurately describe a large class of observations on the basis of a model that contains a few arbitrary elements, and it must make definite predictions about the results of future observations. For example, Aristotle believed Empedocles’s theory that everything was made out of four elements, earth, air, fire, and water. This was simple enough, but did not make any definite predictions. On the other hand, Newton’s theory of gravity was based on an even simpler model, in which bodies attracted each other with a force that was proportional to a quantity called their mass and inversely proportional to the square of the distance between them. Yet it predicts the motions of the sun, the moon, and the planets to a high degree of accuracy.’.

The fact that these definitions for theory in science were in general use and had a common understanding at the time of the first offerings on evolution by Darwin and Wallace is substantiated below by extracts from Noah Webster's *American Dictionary of the English Language* (1828) and the *Oxford English Dictionary* (1989) plus its precursor published in 1888[40]. It will be demonstrated that these definitions guided Darwin and Wallace in their writing.

> ‘The philosophical explanation of phenomena, either physical or moral; as Lavoisier's theory of combustion; Smith's theory of moral sentiments. Theory is distinguished from hypothesis thus; a theory is founded on inferences drawn from principles which have been established on independent evidence; a hypothesis is a proposition assumed to account for certain phenomena, and has no other evidence of its truth, than that it affords a satisfactory explanation of those phenomena (*Webster's American Dictionary of the English Language*, 1827).

> *A scheme or system of ideas or statements held as an explanation or account of a group of facts or phenomena: a hypothesis that has been confirmed or established by observation or experiment and is propounded or accepted as accounting for the known facts; a statement of what are held to be the general laws, principles or causes of something known or observed* (*The Oxford English Dictionary,* Second Edition, 1989; *A New English Dictionary on Historical Principles*, *1888*).

The above denotation of theory is an indispensable driver of science. However, its operation and influence in books by Fisher (1930), Haldane (1932), Huxley (1942) is open to question. These three books slant towards biometry and are regarded as cornerstones of so-called 'neodarwinism' or the 'modern synthesis' of the theory of evolution by natural selection (Ridley, 2004). The same concern applies to numerous other writings on evolution. Semantic confusion around the word 'theory' may also apply to the words ‘nature’ and 'natural' and to many other terms used in the context of evolution. In consequence, there is ample justification for reconsidering the fundamentals of the theory of evolution by natural selection and using the results to construct an ontology or conceptual framework that can inform One Health. The fact that all these writings are in the English language, the vehicular language of science, demands action. Sources of knowledge that are available for universal translation and access must be demonstrably sound if global challenges within the scope of One Health are to be addressed cooperatively and effectively.

[40]Simpson ESC and Weiner JA (Editors)(1989) *The Oxford Encyclopaedic English Dictionary, Second Edition.* Clarendon Press, Oxford.
Murray JAH, Bradley H, Craigie WA and Onions CT (Editors)(1888) *A New English Dictionary on Historical Principles*. Clarendon Press, Oxford. (https://archive.org).

Darwin and Wallace formulated the theory of evolution by natural selection according to questions in biology that prevailed at their time and place; namely, what Darwin referred to as ‘that mystery of mysteries’, the origin of species and why life forms have persisted in the face of changing physical conditions. The phrase ‘origin of species’ implies macroevolution with a focus of speciation and biodiversity and not microevolution or evolution at or below the species level (including genetic systems). Significantly, Darwin (1876) uses the word ‘cell’ only in connection to beehives and makes no mention of ‘metabolism’ and refers to ‘physiology’ not at all in the first two editions of *Origin of Species* and once only in subsequent editions. Cell theory was well in place by 1876 (Mazzarello, 1999) and Virchow's aphorism, ‘*omnis cellula e cellula’* (‘every cell stems from another cell’) was published in 1855 (Schultz, 2008). Theodor Schwann, a proponent of cell theory, coined the term metabolism in 1839 (Bunch and Hellemans, 2004). A conception of the theory of evolution by natural selection without links to cell theory and the concept of metabolism is untenable and has little practical value. Cell theory embodies the properties and attributes that characterise life and underpins both physiology and pathophysiology which are mainstays of One Health.

3.2 Meanings of words relevant to a survey of word use in the literature on evolution

Various dictionaries of the English language have been consulted on the meanings of 'theory', 'nature' and 'natural' and 34 other words selected for their prominence in the theory of evolution by natural selection and for their use in the proposed ontology for natural selection theory. This ontology will be guided by methods adapted from the fields of computer technology and software engineering (Russell and Norvig, 2010) where the clarity of concepts and their coherent relationship is paramount. In effect, meeting the needs of computer technology, software engineering through artificial intelligence can accredit the soundness or otherwise of ideas and propositions.

The *Encarta World English Dictionary* (Rooney, 1999) describes contemporary usage according to the English language as an open and universal resource (McArthur, 1999). Two editions of *Webster's Dictionary* (Webster, 1842; Webster, Goodrich and Porter, 1865) give a view of word usage in Darwin's lifetime. This is complemented by the *Oxford English Dictionary* (Murray et al., 1888 and Simpson and Weiner, 1989). Various other versions of *Webster's Dictionary* and the *Oxford English Dictionary* (*A New English Dictionary on Historical Principles: Founded Mainly on the Materials Collected by the Philological Society*) were consulted via the website archive.org. Lastly, the Wiktionary, a contemporary online and free-content multilingual dictionary (available on the internet at https://en.wiktionary.org) provides a supplementary source of information. The words in question fit into four *ad hoc* categories as listed in Table 4.

Table 4: Words used in a survey of word use in the literature on evolution and in the ontology for the theory of evolution by natural selection according to four *ad hoc* categories.

Category 1: Words relating to general ideas	**Category 2: Words in general use that extend to the living world**	**Category 3: Figurative language used by Darwin *in lieu* of contemporary biological terms**	**Category 4: Terms used in biology and absent from Darwin's *Origin of Species***
1. Behave and behaviour	18. Adapt and adaptation	32. Struggle	34. Ecology
2. Capability and capable	19. Competition	33. Struggle for existence	35. Metabolism
3. Capacity	20. Descend (also Descent)		36. Physiology
4. Concept and conception	21. Environment		
5. Doctrine	22. Fit/Fittest [fitness]		
6. Evolution	23. Hereditary [Heredity]		
7. Function	24. Inherit, [Inheritance]		
8. Hypothesis	25. Population		
9. Mechanism	26. Race		
10. Nature (also Natural)	27. Replicate [Replication]		
11. Perform and Performance	28. Reproduce [Reproduction]		
12. Phenomenon	29. Species		
13. Process	30. Viable [Viability]		
14. Progress	31. Vital [Vitality]		
15. Proposition			
16. prefix -ism (as in Darwinism)			
17. Theory			

Webster's Dictionary (1842), gives four senses of the word 'theory' including one that mirrors the sense currently proposed for science (National Academy of Sciences, 1999; National Research Council, 2008) and which is reiterated for its importance. A theory is 'the philosophical explanation of phenomena, either physical or moral; as Lavoisier's “theory’ of combustion'. Webster's Dictionary (1842) goes on to state that 'theory is distinguished from hypothesis thus; a theory is founded on inferences drawn from principles which have been established on independent evidence; a hypothesis is a proposition assumed to account for certain phenomena, and has no other evidence of its truth, than that it affords a satisfactory explanation of those phenomena'. This provides documentary evidence that the current gist of theory in science was in play at the time of the early work of Darwin and Wallace and and could have been heeded at the time of the modern synthesis of evolution theory in the twentieth century.

The Oxford English Dictionary (1989) has multiple senses of the word 'theory', including one that mirrors the meaning currently proposed for science (NAS, 1999 and 2008). Sense 4a from the Oxford English Dictionary dates to 1638 is also reiterated for its importance and refers to a 'scheme or system of ideas or statements held as an explanation or account of a group of facts or phenomena; a hypothesis that has been confirmed or established by observation or experiments and is propounded or accepted as accounting for the known facts; a statement of what are held to be the general laws, principles or causes of something known or observed'. This sense is corroborated in seven other dictionaries of the English language and, for clarity, will be referred to as Theory A (Science). Theory A (Science) is encapsulated by the National Academy of Sciences (2008) as and this serves as a precising definition for the proposed ontology. Confusion arises because the word theory can also refer to ‘a hypothesis proposed for explanation; hence a mere hypothesis, speculation, conjecture; an idea, set of ideas about something; an individual view or notion’. For clarity, this paradoxical and conflicting use of the word 'theory' will be referred to as Theory B (Idea). Theory C (Principles) as in music theory has an unequivocal and separate sense as the body of rules, ideas, principles, and techniques that apply to a particular subject and inform actual practice. The crucial difference in meaning between theory B (Idea) and Theory A (Science) does not guide works that push for intelligent design. Intelligent design is an argument intended to demonstrate that living organisms were created in more or less their present forms by an intelligent designer’ (https://www.britannica.com/topic/intelligent-design) and is at odds with cogent and reliable theology (Ayala, 2007).

A full understanding of the various meanings of 'nature' and 'natural' also applies to a clear-cut understanding of the theory of evolution by natural selection and partly because Darwin (1872) distinguishes between natural and artificial selection. Similar to 'theory', the Oxford English Dictionary (1989) has multiple senses for 'nature' and 'natural'. Two senses of 'nature' are specially relevant to the present task. These are nature as the 'essential qualities or properties of a thing: the inherent and inseparable combination of properties essentially pertaining to a thing and giving it its fundamental character' (Nature A, Essence) and 'the creative and regulative physical power which is conceived of as operating in the material world and as the immediate cause of all its phenomena' (Nature B, Forces). The adjective 'natural' has a meaning as '*o*f substance or article not made, manufactured or obtained by artificial means'. These meanings of 'nature' and 'natural' are corroborated in seven other dictionaries of the English language.

The English language has become World English (McArthur, 1999), a global resource that can realise the principle of universalism in science (Merton, 1972) and provide common and open access to information for the international community (UNESCO, 2005). With this in mind, Table 5 uses the *Encarta Dictionary of World English* (Rooney, 1999) to list various senses of ‘theory’, ‘nature’ and ‘natural’ and that are foremost in a survey of diction and word choice in the literature on evolution. The *Encarta Dictionary of World English* allocates five distinct meanings to theory and eleven distinct meanings to nature/natural. Meanings 2, 3 and 4 of theory from the *Encarta*

Dictionary of World English overlap and are merged. This conflict of meanings or senses shows that confusion, ambiguity and equivocation are clear-cut hazards within discussions of evolution.

Four tables in Appendix 2 explore the words listed in Table 4 according to their multiple denotative and connotative meanings and when the words came into common use as reported in early editions of *Webster's Dictionary* and the *Oxford English Dictionary.* The tables in Appendix 2 also list where each word occurs in the semantic fields or synonym clusters found in *Roget's Thesaurus* (Lloyd, 1984) and the *Macquarie Thesaurus* (Bernard, 1984). The purpose here is to shed light on possible ambiguities and inconsistencies of use within the literature on evolutionary biology. Some meanings of some words are regarded as inconsequential to the present task and are not included in the tables in Appendix 2. One example is the word 'natural' used in music to denote the absence of sharps or flats. Another is 'evolution' where it refers to giving off heat or gas as in physics. For convenience, entries for the words nature, natural and theory have been extracted from the tables in Appendix 1 and are shown in Table 5. Some definitions of Nature A (Essence)

Table 5: Information about the words 'Nature '[Natural] and 'Theory' used in the survey of word use in selected literature on evolution (extracted from Table A1 in Appendix 2).

Word	**Meaning: Encarta Dictionary of World English**	**Credible date of common use**	**Keyword and semantic fields: Roget's Thesaurus**	**Keyword and semantic fields: Macquarie Thesaurus**	**Comments**
NATURE, NATURAL	Nature A (Essence) Also Natural A INTRINSIC CHARACTER OF PERSON OR THING; the intrinsic or essential character of somebody or something [the inherent character or basic constitution of a person or thing – Merriam Webster Dictionary]	Webster's Dictionary 1828, corroboration OED 1989.	*Intrinsicality character* 5n	*Nature (Essence)* 222.2 *Character* 89.1	This meaning of nature in the sense of Nature A (Essence) will be used in the ontology for the theory of evolution by natural selection– sections .
	Nature B (Forces) Also Natural B FORCES CONTROLLING THE PHYSICAL WORLD; The forces and processes collectively that control the phenomena of the physical world independently of human volition or intervention.	Webster's Dictionary 1828, corroboration OED 1989.	Not present	Not present	Nature B (Forces) is the meaning that applies to Darwin's conception of natural selection. From page 63 of *Origin of Species*: ' *….but I mean by Nature, only*

Word	Meaning: Encarta Dictionary of World English	Credible date of common use	Keyword and semantic fields: Roget's Thesaurus	Keyword and semantic fields: Macquarie Thesaurus	Comments
					the aggregate action and product of many natural laws, and by laws the sequence of events as ascertained by us'
	Nature C (Physical World) PHYSICAL WORLD: The physical world including all natural phenomena and living things.	Webster's Dictionary 1828/ corroborated OED 1989.	*Production, producer* 164n *Materiality, matter* 319n	*Organism, biota* 522.2 *Cosmos (Cosmos)* 146.1 *Cosmos (Tangible)* 736.1 *Life* 447.1 *Nature (Nature)* 494.1	Webster et al. (1865) 'Nature' refers to the existing systems of things or the established or regular course of things and 'natural' means having to do with the existing system or regular course of things.
THEORY	Theory A (Science) SCIENTIFIC PRINCIPLE TO EXPLAIN PHENOMENA: A set of facts, propositions or principles analysed in their relationship to one another and used especially to explain phenomena [late 16thC] 'Comprehensive explanations of aspects of nature that are supported by vast bodies of evidence such that that they can be used to make predictions about natural events or phenomena that have not yet been observed' (National Academy of Sciences, 2008).	Webster's Dictionary 1828, corroboration OED 1989.	Not present	Not present	OED 1989 records the denotative use of Theory A (Science) to 1638, 1706, 1727-41 and 1812 CE. The words 'doctrine' and 'dogma' are not synonyms for Theory A (Science).
	Theory B (Idea) SPECULATION: Abstract thought or contemplation.	Webster's Dictionary 1828, corroboration OED 1989	*Supposition* 512n	*Notion* 497.1 *Credence/ doubt/opinion* 152.2 *Conjecture*	OED 1989 defines Theory B as 'a mental view or contemplation'

Word	**Meaning: Encarta Dictionary of World English**	**Credible date of common use**	**Keyword and semantic fields: Roget's Thesaurus**	**Keyword and semantic fields: Macquarie Thesaurus**	**Comments**
	IDEA FORMED BY SPECULATION: An idea or belief about something arrived at through speculation or conjecture. HYPOTHETICAL CIRCUMSTANCES: a set of circumstances or principles that is hypothetical.			131.2 *Subject Matter/ argument*720.2 *Subject Matter (hypothesis)* 131.2	. Theory B is summed up as 'conjecture or opinion' (Wiktionary)
	Theory C (Principles) RULES AND TECHNIQUES: The body of rules, ideas, principles, and techniques that applies to a particular subject, especially when seen as distinct from actual practice.	Webster's Dictionary 1828, corroboration OED 1989	Not present	Not present	Veterinary medicine combines theory (logos) and art (techne). Game theory comes within the ambit of Theory C (Principles)

The detail in Table 5 and repeated in Appendix 2 allows an appraisal of word choice in influential publications on evolution; firstly, to determine whether the denotation of Theory A (Science) is recognised and utilised and, secondly, to identify the availability of a succinct exposition of the theory of evolution within the 'modern synthesis' and according to Theory A (Science). Some of the dictionary definitions of words set out in the four tables in Appendix 2 are used in section 3.3 to illustrate that the essential elements of the theory of evolution by natural selection are contained comprehensively in Darwin's *Origin of Species*. Section 3.3, augments particular excerpts from *Origin of Species* with meanings of key words that had currency throughout the nineteenth century. The purpose is to assist with translations of the theory of evolution by natural selection from World English to other languages in order to promote universal intelligibility and universal access to knowledge within One Health.

3.3 Usage of the words 'theory', 'nature', 'natural' and so on in selected literature on evolution – a case study

A sample of books from the field of biology that reflect different stages of thought about the theory of evolution by natural selection were searched for the incidence and usage of the words set out in Table 5. The focus on diction in this case study was narrow by design and intended to make

observations that may benefit the proposed ontology for the theory of evolution by natural selection. The informative value of the case study relates to how knowledge around the theory of evolution by natural selection has advanced, how factors associated with time and place and how technical innovations such as IT can influence the enterprise of science.

The search function available in computer application software[41] assisted in the analysis of digitised publications. ‘Theory' and its several denotations had foremost importance. Words related in meaning to Theory B (Idea) were also sought. Examples are 'doctrine', 'hypothesis', 'concept', ‘proposition’ and ‘thesis. The word 'environment' was searched for in relation to its similarity to some meanings of 'nature and 'natural' and because of its central place in the discipline of ‘ecology’, which deals with the interrelationships of organisms and their environments.

The words ‘fit’, ‘fitness’, ‘adapt’ and ‘adaptation’ were investigated. These words had simple, comprehensible and consistent meanings within all editions of *Origin of Species* according to their recorded usage during Darwin’s lifetime. Appendix Table A2 refers to adaptation as 'the act of making suitable, or the state of being suitable, or fit’ and fitness as ‘suitableness, adaptedness, adaptation; as the *fitness* of things to their use’. These words are prime examples of ‘terms in evolutionary biology that, though commonly used, are plagued in their usage by multiple concurrent and historically varying meanings’ (Keller and Lloyd, 1992). Controversies around the term ‘adaptation’ are discussed by Ridley (2012) and Larson (2016). Emerging complexities around the term ‘fitness’ are discussed by Charlesworth (2012) and Stearns (2014).

The words 'viable' and 'viability' and 'metabolism' were investigated because notions of 'survival of the fittest', 'struggle for life' and 'competition' may represent the perspective of earlier times. Notions like ‘struggle for life’ and ‘survival of the fittest’ are inconsistent with current metabolic, physiological, autopoietic and thermodynamic views of life (Sagan, Margulis and Sagan, 2010). The suggestion that evolutionary thinking in engineering and general science may be enhanced through the concept of viability and elimination rather than that of competition and selection (Maesani et al., 2014) may also apply to the theory of evolution by natural selection and the living world. The word ‘fittest’ was also investigated because it is crucial to the phrase ‘survival of the fittest’. This phrase sought to illuminate the *Origin of Species* but it was manipulated to support the ends of eugenics and colonial imperialism[42].

The words ‘race’ and ‘population’ were searched for because the vague meaning of ‘race’ has been blurred by its fabricated connotations. Darwin’s meaning of ‘race’ could be conveyed by ‘population’ or perhaps ‘deme’. The harmful consequences of certain interpretations around ‘race’ have been addressed within UNESCO’s beneficent Declaration on Race and Racial Prejudice

[41]Portable document format (PDF), standardised as ISO 32000, is a prime example.

[42]This excerpt from *The Penguin History of the World* (Roberts and Westad, 2013) illustrates the point: ‘At the base of all these views [about intrinsic racial status and its accompanying entitlement] there was a conviction of superiority and there was nothing surprising about this; it had always animated some imperialists. But in the later nineteenth century it was especially reinforced by fashionable racist ideas and a muddled reflection of what was thought to be taught by current biological science about the survival of the fittest’.

(1978)[43] and conclusions have been reinforced along with gender equality in UNESCO's Declaration of Principles on Tolerance (1995)[44]. 'Population' is an important concept in epidemiology and ecology and the word leads to coherence among the disciplines of epidemiology, ecology and evolutionary biology. A population is an aggregate of creatures, things, cases and so on (Campbell and Swinscow, 2009) and the terms infrapopulation and suprapopulation are used in the discipline of parasitology (Margolis et al, 1982). Bush et al (1997) introduced the notion of component populations.

Lastly, the words 'reproduction [reproduce]' and 'replication [replicate]' were searched for. In this regard, 'reproduction' has a broader meaning than 'replication', which means to reproduce exactly. These two words must be differentiated in order to connect the theory of evolution by natural selection with the central concept of biological organisation. Replication refers to the duplication of informational macromolecules by life forms and reproduction refers to the processes whereby life forms give rise to new individuals of their kind. Life form include viruses and prions.

'Behaviour', 'performance', 'capability' and 'capacity' are added to the list of words because musings around the theory of evolution by natural selection have thrown up a major consideration that will be elaborated later (see section 3.3). This consideration arises because Darwin's proposal for natural selection in *Origin of Species* was inspired by artificial selection (a single mention only) and a multitude of observations from the breeding of animals and plants. The crux is the simple but frequently neglected fact that animal and plant breeders select according to the performance, behaviour, capability and capacity of individual organisms that is displayed and then observed. Observation of the natural world is the pre-eminent driver of knowledge about the natural world. 'Observations are the conduit through which the "tribunal of experience" delivers its verdicts on hypotheses and theories*'*(Boyd and Bogen, 2021).

3.3.1 Word usage in Darwin (1872), The Origin of Species by Means of Natural Selection 6th edition.

The 6th edition of *Origin of Species* contains 147 instances of the word 'theory' and 140 of these are in the text. It is clear that the word is used according to the meaning of Theory A (Science) in most but not all cases. Theory A (Science) is illustrated by an excerpt from Chapter 15 as follows: 'That many and serious objections may be advanced against the theory of descent with modification through variation and natural selection, I do not deny. I have endeavoured to give to them their full force'. 'Descent with modification' sums up the phenomenon of evolution and 'variation and natural selection' provides an explanation. In other words, a scheme, system, conceptual framework or ontology is foreshadowed. Darwin describes his book as 'one long argument', which refers to efforts in marshalling evidence that may allow for a possible theory in the sense of Theory A (Science). Darwin's evidence for the theory of evolution by natural selection comes from many

[43] https://www.unesco.org/en/legal-affairs/declaration-race-and-racial-prejudice

[44] https://www.unesco.org/en/legal-affairs/declaration-principles-tolerance

separate sources and can be viewed as the coherence, corroboration or consilience[45] that makes for reliable conclusions (Whewell, 1840: see Wilson, 1998 and Gauch, 2003).

A particular instance of Theory B (Idea) in *Origin of Species* comes with this quotation from the biologist Hermann von Helmholtz (1821-1894): 'One might say that nature has taken delight in accumulating contradictions in order to remove all foundation from the theory of a pre-existing harmony between the external and internal worlds'. Darwin also refers to the theory of creation in several places and the sense here can be regarded as Theory B (Idea). No instance of Theory C (Principles) can be found. Darwin treats the theory of natural selection (38 textual mentions) and the theory of descent with modification (evolution)(15 textual mentions) as separate entities and mentions the theory of evolution by natural selection once only. Romanes merges natural selection and evolution and talks of the theory of evolution by natural selection in his books *The Scientific Evidences of Organic Evolution* (1882) and *Darwin, and after Darwin* (1910)

The word 'doctrine' has eight mentions but none in the sense of Theory A (Science). Darwin refers to the geometrical ratio of increase and its application to the animal and vegetable kingdoms as the doctrine of Malthus. Doctrine refers to principles taught, advocated or stemming from vested authority and like 'dogma' is not commensurable with Theory A (Science) nor is it compatible with the practice of science or discourse around science.

'Nature' is used 325 times and according to the three meanings mentioned earlier; 'essential qualities or properties of a thing' (Nature A, Essence), the 'regulative physical power... operating in the material world' (Nature B, Forces) and Nature C (Physical World). Nature A (Essence) is implied in this excerpt from Chapter 1 of *Origin of Species* (6th Edition): '… and as I have incidentally shown in my work on "Variation under Domestication", there are two factors: namely, the nature of the organism, and the nature of the conditions [of life]'. An example of Nature C (Physical World) is found in the following excerpt referring to the breeding of pigeons: 'I felt fully as much difficulty in believing that since they had been domesticated they had all proceeded from a common parent, as any naturalist could in coming to a similar conclusion in regard to the many species of finches, or other groups of birds, in nature'.

Nature B (Forces) is evident in Darwin's use of a quote from William Whewell (1794-1866) at the start of *Origin of Species* (6th Edition): 'But with regard to the material world, we can at least go so far as this—we can perceive that events are brought about not by insulated interpositions of Divine power, exerted in each particular case, but by the establishment of general laws'. This quote from Whewell signifies the essence of Darwin's concept of natural selection and its foundation in Nature B (Forces). Darwin aptly describes evolution as 'descent with modification'. In consequence, the theory of evolution could be expressed as descent with modification resulting from 'the forces and processes collectively that control the phenomena of the physical world independently of human volition or intervention'; in other words, as a result of Nature B (Forces).

[45]The word 'consilience' is absent from the Encarta Dictionary of World English and from several other popular dictionaries of English. It is a synonym for more commonplace words like 'corroboration' or 'confirmation'.

3.3.2 Word usage in Wallace (1889), Darwinism

It is unclear whether Wallace or his publisher appreciated the polysemous nature of the word 'theory'. The denotation of Theory A (Science) operates at the end of Chapter 5*:* 'We have now passed in review, in more or less detail, the main facts on which the theory of "the origin of species by means of natural selection" is founded'. The title *Darwinism*, however, is problematical because of the prefix -ism. This prefix usually refers to a 'doctrine or system of beliefs' (*Encarta Dictionary of World English*, 1999). The notion of 'doctrine' as something taught or advocated is at odds with the world view of science which contends that 'the things and events in the universe occur in consistent patterns that are comprehensible through careful systematic study' (American Association for the Advancement of Science, 1990).

Wallace (1889) implies Theory B (Idea) when he refers to 'the theory of instinct', 'the theory of progressive development' and when he splits the theory of evolution by natural selection in two and refers to the theory of evolution in 14 places and the theory of natural selection in 13 places. This signals that *Darwinism* was not written around an unequivocal conception of Theory A (Science).

As to consistency between accounts of the theory of evolution by natural selection, Wallace and Darwin address the same theme and their work converges on the same general conclusions. Wallace invokes evidence additional to that of Darwin to corroborate and fortify the general thrust of the theory of evolution by natural selection and to elucidate the processes involved. Consilience or the convergence of evidence from different sources (Wilson, 1998; Gauch, 2003) is in play.

Wallace uses the word 'environment' in 62 places. This word and its implications for Nature C (Physical World) was not employed by Darwin in the *Origin of Species*. Instead, Darwin repeatedly employed the phrase, the 'conditions of life', which may have encompassed both internal environment of the life form as well as its surroundings. Thanks to Wallace, the word 'environment' adds clarity to the concept of natural selection and moves its consideration to a different level. An example of the use of 'environment' is in Chapter 14 of Wallace's *Darwinism*: 'So that the statement that plant modifications proceed "along an absolute groove of progressive change" is contradicted by innumerable facts indicating advance and regression, improvement or degradation, according as the ever changing environment renders one form more advantageous than the other'. Additionally in Chapter 14, Wallace connects the word 'environment' to the work of Carl Semper (1832-1893), an early ecologist, and establishes a possible early reciprocity between evolutionary thinking and ecology.

3.3.3 Word usage in Spencer (1887 and 1898)

Two works of Herbert Spencer were viewed: *The Factors of Organic Evolution* (1887) and *The Principles of Biology* (1898 – American Edition 1910). The first is an opinion piece which looks at some imaginable implications of the theory of evolution by natural selection for psychology, ethics,

and sociology. Its treatment of biology is secondary and not extensive. Accordingly, the present analysis focuses on Spencer's book, *The Principles of Biology.*

The Principles of Biology contains 40 mentions of theory. Most seem to mean theory in the sense of 'a proposed explanation whose status is still conjectural' (Theory B, Idea) and only one instance may imply Theory A (Science). This occurs in Chapter 2: 'That the first living things were minute portions of simple protoplasm is implied by the general theory of Evolution; but we have no evidence that such portions exist now'. 'Doctrine' is mentioned 50 times, including 10 references the 'doctrine of evolution'. Spencer refers to the cell-doctrine and doctrine of metabolism and its 'Hypothesis' is mentioned 220 times, including 30 references to the 'hypothesis of evolution'. The overall conclusion is that Spencer's writing on evolution is not framed with a clear view of the concept of Theory A (Science).

3.3.4 Word usage in Fisher (1930), Haldane (1932), Wright (1922 to 1987) and Huxley (1942)

The works of Fisher (1930), Haldane (1932), Wright (1922 to 1978; collated by Wright and Provine, 1986) and Huxley (1942) are considered together because they are widely recognised for their contribution to what is termed the evolutionary synthesis, the modern synthesis or neo-Darwinism (Futuyma and Kirkpatrick, 2017; Ridley, 2004). These three terms refer to the installation into evolutionary thinking of knowledge about genetics that was unavailable to Darwin and Wallace. Allen (2014) describes the evolutionary synthesis as a 'term usually applied to developments in evolutionary theory between roughly 1930 and 1950 or 1960, and characterised by the union of Darwinian evolutionary theory with Mendelian genetics (as population genetics), taxonomy, and palaeontology'. Put simply, the modern synthesis made connections to emerging biological knowledge and explored possible mechanisms for the capabilities that allow evolution by natural selection. Darwin (1872) identified these capabilities as reproduction, variability and inheritance[46]. Van Whye (2008) recognises the importance of concept hierarchies and notes that 'explaining the complexities of genes and DNA [i.e. molecular mechanisms] is not necessary to understand the basic fact of evolution'.

The Genetical Theory of Natural Selection (Fisher, 1930) mentions the word 'theory' 154 times and the first mention in the Preface is supremely pertinent in the present context. Here Fisher says: 'Selection is not Evolution. Yet, ever since the two words have been in common use, the theory of Natural Selection has been employed as a convenient abbreviation for the theory of Evolution by means of Natural Selection, put forward by Darwin and Wallace. This has had the unfortunate consequence that the theory of Natural Selection itself has scarcely ever, if ever, received separate consideration'. This statement does not recognise the common-sense distinction between the

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[46] From page 429 of *Origin of Species*:'These laws, taken in the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the conditions of life, and from use and disuse: a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less improved forms'.

phenomenon of ‘evolution’ and the explanation provided by the process of ‘natural selection’. Furthermore, it does not build from the meaning attached to Theory A (Science) and implies that Fisher’s overall use of the word ‘theory’ concerns Theory B (Idea). Fisher goes on to mention ‘blending theory’, ‘particulate theory’, ‘mimicry theory’, ‘Müllerian theory’. ‘theory of saltation’, ‘Mendelian theory’, ‘theory of sexual selection’ and ‘Spencer’s theory’, all of which relate to Theory B (Idea). Finally, the word ‘theory’ is used ambiguously in the title of Fisher’s book.

A major theme in Fisher’s *The Genetical Theory of Natural Selection* is concern that ‘the socially lower occupations [of people] are the more fertile’ and that ‘we must face the paradox that the biologically successful members of our society are to be found principally among its social failures’. This is absurd given that the theory of evolution by natural selection concerns biology. Fisher also states that ‘classes of persons who are prosperous and socially successful are, on the whole, the biological failures, the unfit of the struggle for existence, doomed more or less speedily, according to their social distinction, to be eradicated from the human stock’. The ‘social failures’ include ‘coal-miners; other miners; farm labourers; farmers; building labourers; railway labourers; railway construction foremen; metal moulders; and factory labourers’. These are the people who provide food and infrastructure for society and an environment where the ‘higher ranks of the professional and official classes’ can flourish.

According to Wright (1978), Fisher’s achievement was to give mathematical form to a proposal that ‘evolution is due primarily to mass selection of quantitative variability’. Fisher’s book qualifies as an opinion piece rather than a disinterested and rigorous review of knowledge that meets current norms of conduct in science (Interacademy Partnership, 2016). The book is dedicated to the sponsor of the British Eugenics Society (Major Leonard Darwin, the son of Charles Darwin) and its content and thrust are directed towards a eugenics agenda. Fisher (1930) is concerned that ‘the language of evolutionary writers [this includes Darwin and Wallace] has endowed the word “success” with a biological meaning, by bestowing it upon those individuals or societies, who, by their superior capacity for survival and reproduction, are progressively replacing their competitors as living inhabitants of the earth’. ‘Success’ necessitates a biological meaning because successful or effective ‘descent with modification’ occurs in Nature C (Physical World) and is driven by Nature B (Forces); ‘the forces and processes collectively that control the phenomena of the physical world independently of human volition or intervention’. ‘Success’ in this biological sense runs counter to Fisher’s conviction that ‘success in human endeavour is inseparable from the maintenance or attainment of social status’. Fisher (1930) demonstrates a lack of objectivity, which according to Gauch (2003) joins rationality, truth and realism as one of science's four claims[47].

The Causes of Evolution (Haldane, 1932) contains 44 instances of 'theory', six instances of 'doctrine', twelve instances of ‘hypothesis’, 39 instances of ‘nature’, and 84 instances of natural. There is no unequivocal instance of Theory A (Science). The word ‘theory’ in the opening sentence of the book implies Theory B (Idea) and the second sentence of the book refers to the ‘doctrine’ of

[47]Objectivity: Objective beliefs concern physical objects: they can be tested and verified so that consensus will emerge among knowledgeable persons; and they do not depend on controversial presuppositions or special worldviews.

evolution. Page two contains the sentence that: 'We must therefore carefully distinguish between two quite different doctrines which Darwin popularised, the doctrine of evolution, and that of natural selection'. Haldane like Fisher fails to recognise the crucial semantic distinction between 'doctrine', which proceeds from authority, and Theory A (Science)', which proceeds from reasoning and evidence. Furthermore, Haldane like Fisher is not cognisant that the phenomenon of 'evolution' goes with 'natural selection' to become 'a coherent statement or set of ideas that explains observed facts or phenomena and correctly predicts new facts or phenomena not previously observed' (Wiktionary, https://en.wiktionary.org)'; in other words, Theory A (Science).

Evolution: The Modern Synthesis (Huxley, 1942) contains 65 mentions of theory, eight mentions of doctrine, 283 mentions of nature, 153 mentions of natural and 82 mentions of natural selection. Two mentions of doctrine relate to the theory of evolution. They point to confusion about Theory A (Science). A sentence on page 27 states: 'According to the Darwinian doctrine, evolution is an essentially continuous process, and selection is essentially creative in the sense that no change would occur if selection were removed'. Two sentences on page 390 state that: 'In the first or Linnaean period, the underlying principle was the separate creation of species. In the second or Darwinian phase, it was the doctrine of descent with modification'. As a consequence, it is apparent that 'theory' in the sense of Theory A (Science) does not operate unreservedly in *Evolution: The Modern Synthesis*.

Evolution: The Modern Synthesis (Huxley, 1942), like *The Causes of Evolution* (Haldane, 1932), does not reflect upon the possible application of evolutionary thinking to the ends of health and agriculture. However, these two books mention the environment, ecology, metabolism and viability and foreshadow another stage in the development of evolutionary thinking; one that brings it closer to the needs of One Health, including agriculture.

The works of Sewall Wright considered here date from 1922 to 1978 and have been collated into a single publication (Wright and Provine, 1986). This body of work forms an essential contribution to the mathematical formulations that tested the fundamentals of the theory of evolution by natural selection and created the so-called modern synthesis (Hull, 2002). Wright's repeated statements that the practical knowledge of plant and animal breeders is a major resource for evolutionary biology are a mark of distinction. They support the notion of reciprocity between evolutionary and One Health that has been explored in section 2.7.

Evolution: Selected Papers (Wright and Provine, 1986) is a collation of 42 papers written between 1922 and 1978. These contains 432 mentions of theory, 68 mentions of hypothesis, three mentions of doctrine, 137 mentions of 82 nature, 321 mentions of natural and 252 mentions of natural selection. The mentions of hypothesis, doctrine, nature, natural and natural selection require no comment. However, it is clear that the word theory does not consistently refer to Theory A (Science). Theory B (Idea) applies to Wright's references to the shifting balance theory, Fisher's theory of dominance, the theory of punctuated evolution, multiple factor theory, de Vries' theory, Willis' theory, Goldschmidt's theory, theory of isolation by distance, and the theory of area

continuity. These theories or ideas have been overtaken by advances in knowledge. Wright may have implied Theory C (Principles) in reference to a book by Fisher (1949), *The Theory of Inbreeding* (Fisher, 1949).

The overall conclusion is that neither Fisher, Haldane, Huxley nor Wright framed their accounts of evolution explicitly around the concept of Theory A (Science). These authors may have usefully explored the connections between the newer knowledge of genetics and Darwin's exposition of the theory of evolution by natural selection. However, they provide no concise summary that could be considered a revamped theory of evolution according to what is termed the modern or evolutionary synthesis and in line with the meaning of Theory A (Science). This constitutes a critical defect; that is a defect which make a product unusable and a possible source of harm (see section 2.3). The works of Fisher, Haldane, Huxley and Wright are products of a so-called paradigm, an idea that figured in reflections on the nature of science in the later twentieth century (Kuhn,1962). This sense of a paradigm refers to a structure of world views, presuppositions, methods and standards shared by a particular community of science practitioners at a particular time. The paradigm guiding Fisher, Haldane, Huxley and Wright can be rejected.

Fisher, Haldane and Huxley rely with some confidence on mathematical reasoning or analysis in support of their elaboration of the modern synthesis. Nowadays, this line of mathematical argument would be referred to as mathematical modelling and would be evaluated according to the soundness of its foundational premises and with a view to the aphorism that all models are wrong and some models are useful (Box et al., 2005). Note here also that mathematics deals with spatial and numerical relationships whereas ordinary languages 'describe the sorts of things in the world' (Hogben, 1968). Theories in science build upon sorts of things like 'facts, laws, inferences, and tested hypotheses*'* (National Academy of Sciences, 1999) and verbal precision is vital for application of the theory of evolution by natural selection in One Health. Wright stands apart from Fisher, Haldane and Huxley by clearly and usefully expressing a concern that the theory of evolution by natural selection should be united with applied biology as a source of direct and reliable observation. This reflects the usual sequence in the scientific method, which is observation followed by reasoning and then by experimentation or testing (Feynman et al., 2011).

3.3.5 Word usage in Smith (1993), Mayr (2001) and Gould (2002)

The Theory of Evolution (Smith, 1993) contains no allusion to Theory A (Science) and no capsule description or thumbnail of the theory of evolution by natural selection. The book employs Theory B (Idea) to bring game theory to bear on aspects of evolutionary biology. Game theory is a theory in the sense of Theory C (Principle) and its links to evolution were explored in an earlier book (Smith, 1982). Game theory is a branch of mathematics that studies strategic interactions where the outcomes for participants depend on their own choices and the choices of others. Game theory is employed to predict or prescribe optimal decision-making in competitive or cooperative scenarios and can be a useful adjunct to observations of life forms which connect it to reality and protect it from superficiality (Gradwohl and Parker, 2023).

What Evolution Is (Mayr, 2001) and *The Structure of Evolutionary* Theory (Gould, 2002) are considered together because they come from authors whose research experience concerns taxonomy and ornithology (Mayr), and paleontology (Gould); and whose perspective may weigh towards macroevolution rather than microevolution. To explain, macroevolution is generally regarded as large-scale evolutionary change, ranging from the origin of species and major new features (e.g., novel traits or even new body plans) and microevolution generally refers to inherited change in the characteristics of a group of organisms across generations that occurs within populations and species (Kingsolver and Pfennig, 2014). These definitions of macroevolution and microevolution do not cater for viruses, viroids and prions and demonstrate why a rethink of the theory of evolution by natural selection can benefit One Health.

What Evolution Is' (Mayr, 2001) contains 125 instances of the word 'theory' but no mention of the words 'doctrine' or 'orthodox'. A statement from the Foreword of the book suggests that Mayr does not recognise Darwin's theory of evolution by natural selection as a comprehensive whole and which proposes evolution as a phenomenon and natural selection as a causal process: 'Eventually, Darwin argued that the fascinating world of life had gradually evolved by natural processes from the simplest kinds of bacteria-like organisms, and he backed up his claim by presenting a well-thought-out theory of evolution. Most importantly, he also proposed a theory of causation, the theory of natural selection'. The two uses of theory here relate to Theory B (Idea). When combined they amount to Theory A (Science).

The Foreword of *What Evolution Is* (Mayr, 2001) goes on to say that Darwin proposed four theories about the how and why of evolution. The subsequent text refers to Darwin's theory of branching evolution, theory of common descent, theory of variation and selection and theory of gradualism. These instances reflect the meaning of Theory B (Idea). Once again, however, they can be re-assembled into comprehensive whole to form Theory A (Science).

The Structure of Evolutionary Theory' (Gould, 2002) contains 2,730 instances of the word 'theory', 62 instances of the word 'doctrine', and a remarkable 157 instances of the words 'orthodox, orthodoxy and orthodoxies'. These are augmented by 10 instances of 'heresy/heretical/heretic', eight instances of 'heterodox/heterodoxy' and 15 instances of 'apostasy' or failure of allegiance. The many instances of 'doctrine', 'orthodoxy', 'heresy/heretical/heretic', 'heterodoxy' and 'apostasy' signify that discussion around evolution during the nineteenth and twentieth century could, at times, be partisan and authoritarian rather than dialectical and collegial. None of Gould's 2,730 instances of 'theory' reflects unequivocally the meaning denoted by Theory A (Science). Nevertheless, the title, *The Structure of Evolutionary Theory*, implies that there is a cohesive whole that can be recognised as Theory A (Science). Earlier on, Gould (1981) described evolution as fact and theory where 'theories are structures of ideas that explain and interpret facts'. This statement foreshadows the reinstatement of Theory A (Science) into the workings of evolutionary biology.

At first glance, the works of Smith (1993), Mayr (2001) and Gould (2002) appear reflect a paradigm that assumes a dichotomy between microevolution and macroevolution. Such a paradigm is untenable. Mayr (2001), however, makes the following statement that merges macroevolution and microevolution: ‘It is important to emphasize that all macroevolutionary processes take place in populations and in the genotypes of individuals, and are thus simultaneously microevolutionary processes’.

3.3.6 Word usage in contemporary text- and guide- books

Explanations of the word ‘theory’ as it applies within science (National Academy of Sciences, 1998 and 1999; National Research Council, 2008) provide a reference point for considering the contents of seven contemporary textbooks. The findings shown in Box 4 below demonstrate progress from the absence of Theory A (Science) in the works of Spencer (1887 and 1889) Fisher (1930) Haldane (1932) and Huxley (1942) to the promulgation of Theory A (Science) by Mayr (2001) and then to the conclusive use of Theory A (Science) in contemporary textbooks on evolutionary biology (Hall et al., 2014; Zimmer and Emlen, 2016; Futuyma and Kirkpatrick, 2017). In short, current circumstances warrant the development of an ontology for the theory of evolution by natural selection grounded on Theory A (Science).

Box 4. Contemporary text- and guide- books confirm the utilisation of Theory A (Science) in evolutionary biology

Re-affirmation of Theory A (Science) in contemporary evolutionary biology

1. Evolutionary Analysis (Freeman and Herron, 2001 and 2014) states that:

(1) ‘The theory of evolution by natural selection is the hypothesis that descent with modification is caused in large part by the action of natural selection’.
(2) This combination of ‘theory’ and ‘hypothesis’ confounds Theory A (Science) and Theory B (Idea) and does not represent the meaning of theory in the practice of science.

2. Evolution, Third Edition (Ridley, 2004) may intimate the notion of Theory A (Science) in the preface that states:

(1) ‘The principal interest, I believe, of the theory of evolution is as a set of ideas to think about, and I have therefore tried in every case to move on to the ideas as soon as possible’.

3 Evolution (Barton et al., 2007) confirm the use of Theory A (Science) in the following two extracts:

(1) ‘Popular debate over evolution and its mechanism is marked by confusion over the scientific use of the terms “fact” and “theory.” Sometimes, it is said that evolution is “only a theory,” suggesting that it is a mere

Re-affirmation of Theory A (Science) in contemporary evolutionary biology

speculation, with little support. In science, however, a theory means a web of interconnected hypotheses, which makes predictions that are consistent with what we see and makes new predictions that stimulate further research. A theory that has survived many different tests may be so well supported that we take it as a fact. This applies to the theories of gravitation, of plate tectonics, of quantum mechanics, and of evolution—all are treated as thoroughly established facts. The fact of evolution is explained by a sophisticated body of theory that shows how it has come about. Much is firmly established. We understand how all the evolutionary processes work, and we have very many examples where we understand how they have generated adaptation and divergence.'

(2) Theory (from Glossary): 'A set of interconnected hypotheses that leads to testable predictions.'

4. *Strickberger's Evolution* (Hall, Hallgrímsson and Strickberger, 2014) recognises the meaning of Theory A (Science) and signals that a concise summary of the theory of evolution by natural selection is possible. An extract from page 12 demonstrates the point:

(1) 'The theory of evolution accounts for the historical sequence of organisms through time. It explains their existence through processes that cause changes in their genetic inheritance over time. The theory of evolution is is a coherent explanation of the historical course of biology (facts) resulting from natural processes such as mutation, selection, genetic drift, migration, and alterations in how genes function. These explanations are consistent with all observations made so far. For these reasons, evolution is a science'.

5. *The Princeton Guide to Evolution* (Losos, 2014) is a book by multiple authors and the following two extracts illustrate the use of Theory A Science):

(1) In the Chapter on the evidence for evolution, Mayer (2014) states: 'In science, a theory is not a mere conjecture but a connected series of propositions supported by, and explanatory of, many and varied lines of evidence. We refer to the 'germ theory of disease' not because we are unsure that microbes cause disease but because the theory is a set of high-level and powerful generalizations that account for and are, in turn, supported by a huge amount of data. Regarding evolution, it was Darwin who first convincingly assembled the many and varied lines of evidence that could be accounted for by, and provide evidence of, descent with modification'.

(2) In the Chapter on selection in populations, Holsinger (2014) states: 'In short, the theory of evolution by natural selection provides a richly textured framework by which to understand an enormous diversity of evolutionary phenomena'.

6. *Evolution, Making Sense of Life* (Zimmer and Emlen, 2016) provides an illuminating view of Theory A (Science) in relation to evolution as shown by the extracts below:

(1) 'A theory is an overarching set of mechanisms or principles that explain a major aspect of the natural world. Many theories develop from tentative explanations or ideas called hypotheses. And even though the word hypothesis sounds closer to the idea of a guess, it is grounded in evidence. Testing and verification lead to greater understanding and explanation. Ultimately, a theory makes sense of what would otherwise seem like an arbitrary, mysterious collection of data. And a theory is supported by independent lines of evidence'.

(2) 'Modern science is dominated by theories, from the theory of gravitation to the theory of plate tectonics to the germ theory of disease to the theory of evolution. Each of these theories came about when scientists surveyed

Re-affirmation of Theory A (Science) in contemporary evolutionary biology
research from experiments and observations and proposed an explanation that accounted for them in a consistent way. Scientists can use theories to generate hypotheses, which they can test with new observations and experiments. The better a scientific theory holds up to this sort of scrutiny, the more likely it is to become accepted. At the same time, however, many theories have been revised with the discovery of new evidence'. (3) 'A good theory is like a powerful flashlight helping scientists make their way into the dark'. (4) 'For scientists, a good theory organizes facts and laws, changing them from a loose collection of details into a meaningful, well-supported picture of the past and a valuable tool that shapes important tests for the future'. 7. *Evolutionary Biology (*Futuyma and Kirkpatrick, 2017) provides a further illuminating view of Theory A (Science) as shown by two extract from Chapter 1: (1) 'Strictly speaking, a scientific theory is a comprehensive, coherent body of interconnected statements, based on reasoning and evidence, that explain some aspect of nature—usually many aspects. Thus atomic theory, quantum theory, and the theory of plate tectonics are elaborate schemes of interconnected ideas, strongly supported by evidence, that account for a great variety of phenomena. "Theory" is a term of honor in science; the greatest accomplishment a scientist can aspire to is to develop a valid, successful new theory.' (2) 'Like all theories in science, it [the theory of evolution by natural selection] is a work in progress, for we do not entirely know the causes of all of evolution, or of all the biological phenomena that evolutionary biology will have to explain. In evolutionary biology, as in every other scientific discipline, there are "core" principles that have withstood skeptical challenges and are highly unlikely to require revision, and there are "frontier" areas in which research actively continues. Some widely held ideas about frontier subjects may prove to be wrong, but the uncertainty at the frontier does not undermine the core'.

3.3.7 Implications of word usage in selected works on evolution

The survey of diction or word use in selected works on evolution was motivated by the thought that sharpened clarity around concepts could expedite a broader application the theory of evolution by natural selection in veterinary medicine and One Health. Two findings loom large. First, ambiguities and the use of figurative language to explain biological concepts are obvious in early documents and harm their intelligibility in the twenty first century. Second, the vocabulary and knowledge available to Darwin and Wallace had clear affect on their portrayal of the theory of evolution by natural selection. For instance, Darwin and Wallace had no recourse to words such as 'environment', 'viable' and 'viability' according to their current meaning and operational value These findings argue for using an ontology to renew the theory of evolution by natural selection and giving it the same utility and soundness as the cell theory and the germ theory of disease.

a. <u>Theory</u>

Usage of the word 'theory' in selected works was illuminating. Theory A (Science) operated clearly in Darwin's *Origin of Species* and has been reinstated in contemporary text and guide books. Usage of theory in the sense of Theory A (Science) was equivocal or misunderstood in earlier works.

Fisher (1930) uses theory only in the sense of Theory B (Idea). Haldane (1932) clearly does not employ theory in the sense of Theory A (Science) and also confounds Theory B (Idea) with the notion of doctrine. Doctrines, things taught or credos, are inconsistent with science viewed as organised scepticism (Merton, 1973; May, 2011). Huxley (1942) also confounds Theory B(Idea) and doctrine and does not clearly refer to Theory A (Science). This state of affairs improves to different degrees in works by Smith (1993), Mayr (2001) and Gould (2002). Significantly, two recent dictionaries on evolution (Pagel, 2002; Kliman, 2016) contain no explicit reference to or explanation of the word 'theory' in the sense put forward by the National Academy of Sciences (1998 and 1999) and the National Research Council (2008).

The upshot is that three influential works on the evolutionary synthesis, the modern synthesis or neo-Darwinism are without a succinct and comprehensible version of the theory of evolution by natural selection built upon Theory A (Science) and that the denotation of Theory A (Science) has been incompletely acknowledged within evolutionary biology. This deficiency has repercussions for a shared understanding of the theory of evolution by natural selection and provides yet another reason for the proposed ontology for natural selection theory. According to the principles of quality control (Evans and Lindsay, 1989), imprecise use of the word theory constitutes a critical defect that makes a product unusable and a possible source of harm.

The negative conclusion coming from imprecise use of the word 'theory' and ignorance of Theory A (Science) does not, however, downgrade the crucial importance of the modern synthesis or neo-Darwinism in removing impediments to progress in evolutionary biology and providing a platform for further advances in knowledge (see Box 5). On the other hand, this conclusion undermines the authority of the modern synthesis, identifies it as a passing phase in the history of evolutionary biology and vindicates current efforts for renewal. The fact that Darwin was precise in his use of Theory A (Science) within *Origin of Species* provides a sound basis for reconciling the theory of evolution by natural selection with present-day biological knowledge.

Box 5. Achievements of the modern synthesis or neo-Darwinism for evolutionary biology

According to Ridley (2004), the evolutionary or modern synthesis reconciled the Darwin-Wallace theory of evolution by natural selection with Mendelian genetics. Mayr (2001) refers to four accomplishment of the evolutionary or modern synthesis.

1. First is the extinction of three schools of thought that competed with natural selection. These were:
   - (1) orthogenesis or the view that life forms have an inbuilt and predetermined tendency to evolve along particular pathways according to final goals,
   - (2) transmutationism and saltationism where evolutionary change and the genesis of new species comes through sudden jumps and
   - (3) a particular view of the inheritance of acquired characters that predated knowledge about informational macromolecules.
2. Second, the modern synthesis allowed a meeting of minds between proponents of particular view of adaptation (anagenesis) and proponents of organic diversity (cladogenesis).

3. Third, the modern synthesis revived and affirmed Darwin's emphasis on variation and selection as the nub of evolutionary change.
4. The modern synthesis empowered research into informational macromolecules, mobile genetic elements and epigenetics and, in doing so, set the scene for a new phase in evolutionary biology.
    - This new phase is intimated within the so-called 'third way of evolution' (Shapiro and Noble, 2021)[48].

b. Nature and natural

Usage of the words 'nature' and 'natural' in the selected works on evolution has particular implications for packaging the theory of evolution by natural selection for use in One Health. Darwin refers to Nature B (Forces) in the prologue to *Origin of Species* by quoting the theologian, William Whewell (1794-1866), that 'divine power' acts through general laws. Darwin could also have quoted another theologian, Albertus Magnus (ca.1200-1280) who stated that 'the world was comprehensible to humans because the same good God made both the physical world and those humans, with their senses and minds suitable for comprehending the world around them' (Gauch, 2003). This view of Nature B (Forces) is a critical presupposition in the practice of science; namely, that 'the world is understandable and that the things and events in the universe occur in consistent patterns that are comprehensible through careful, systematic study' (American Association for the Advancement of Science, 1990). This foundational presupposition applies to the present effort and opens the opportunity for recasting natural selection in terms only of Nature A (Essence) and Nature C (Physical World). Gauch (2003) expounds a full disclosure model of science (the PEL model), whereby 'presuppositions (P), evidence (E), and logic (L) combine to support scientific conclusions.' Foundational presuppositions, once stated, can operate silently. As a consequence, the present effort can concentrate on evidence (E) and logic (L) in pursuing its aims.

Significantly, Darwin uses Nature A (Essence) early in *Origin of Species* when he refers to 'nature of the organism, and the nature of the conditions [of life]' under the heading Causes of Variablity'. This usage will be employed in the proposed ontology for the theory of evolution by natural selection.

c. Reproduction and replication

The related words 'reproduction' and 'replication' were pursued because they shed light on deliberations about evolution in the latter part of the twentieth century. The word 'reproduction', meaning the production by living organisms of new similar organisms, operated in all literature surveyed starting with *Origin of Species*. The word 'replication', however, did not appear until Huxley (1942) where the single entry had a specialised usage regarding polyploidy in a plant belonging to the sunflower family. Nowadays and following the double-helix model of DNA (Watson and Crick, 1953), 'replication' (in the sense of copying) is essential for understanding how genetic information operates within biological systems. The phrase 'DNA makes RNA, and RNA

[48] See website http://www.thethirdwayofevolution.com/.

makes protein' gives a crisp view of replication and its connection to information processing (Watson, 1965)[49].

Incidentally, the related words 'reproducibility' and 'replicability' have another specific meaning in connection with sound practice in science (National Academies of Sciences, Engineering, and Medicine, 2019). Here, reproducibility refers to computational reproducibility; that is, obtaining consistent computational results using the same input data, computational steps, methods, code and conditions of analysis. Replicability refers to the consistency of results cross studies aimed at the same question. Generalisability is an associated concept and refers to the extent that results of a given study apply to other context and populations. Theory in the form of Theory A (Science) and according to the explicit and distinctive meaning of the word theory as it applies within science (National Academy of Sciences, 1998 and 1999; National Research Council, 2008) builds upon the concept of generalisability.

d. Figurative language

Figurative language presents as an impediment the intelligibility of the theory of evolution by natural selection and is particularly apparent in the selected works published before the start of the 21st Century. Darwin and Wallace perhaps needed to use figurative language, such as 'struggle for life', because they were unaware of the metabolic, physiological, biochemical, genetic, thermodynamic, and autopoietic conceptions of life (see Sagan, Margulis and Sagan, 2010). In addition, the word 'viable' or capable of life, which could have replaced figurative language, did not have clear currency and a full breadth of meaning until the twentieth century. The words 'vital' and 'vitality' were available to Darwin. It is conceivable, however, that he shied away from their use because of their mystical and magical connections. This proposition is compatible with Darwin's pursuit of truth within his 'one long argument' and the guiding quotation in the prologue to *Origin of Species* that 'divine power' acts through general laws (William Whewell, 1794-1866).

Similar restrictions on the vocabulary available to Darwin and Wallace may also apply to the concepts of 'environment' and 'ecology'. 'Environment' could have been used wherever Nature C (Physical World) was implied. 'Ecology' denoting the interrelationship of organisms and their environments was coined as a term in 1869 by the biologist, Ernst Haeckel (1834-1919); see Odum, 1983. Its use could have transformed the wording of *Origin of Species* because evolution is an outcome of interactions between organisms and environments.

Figurative language in the literature on evolution after 1953 is exemplified by the construct of the 'selfish gene', which was introduced by Dawkins (1976 and 1983) and succeeded in opening new vistas and provoking discussion that accelerated the advancement of knowledge. On this note, Midgley (1979) stated that 'genes cannot be selfish or unselfish, any more than atoms can be

[49]This phrase is termed the 'central dogma of molecular biology'. The word dogma is problematical and its confusion with the word 'theory' has harmed the scientific literature around evolution. Dogmas are principles or sets of principles laid down by an authority as incontrovertibly true.

jealous, elephants abstract or biscuits teleological'. Baverstock (2021) and Noble (2006, 2017 and 2021) maintained that further insights into the theory of evolution by natural selection were possible without recourse to the construct of selfishness and the 'selfish gene'. Lastly, Shapiro and Noble (2021) were concerned that personifying genes as 'selfish' may confuse an understanding of how the theory of evolution by natural selection operates for viruses, prions and neoplasia and may be incompatible with emerging concepts like the read-write genome (Shapiro, 2017a and 2017b).

The word selfish, however, has connotations (other than egocentrism) that can be explained according to the idea of agency, which is dealt with in Section 4.2.3. These connotations arise because the suffix '-ish' means 'having the qualities or characteristics of' and 'self' can refer to 'a person or things own individuality or essence'[50]. In effect, the selfish gene concept of Dawkins (1976 and 1983) signals the qualities that shape the individuality of a particular life form and its capacity to act. Note here that an agent 'is a being with the capacity to act' and … "agency" denotes the exercise or manifestation of this capacity' (Schlosser, 2015). The term 'selfish' can be reconciled with the more recent notion of agency and need not be encumbered by the connotation of 'egocentrism'.

The phrase 'survival of the fittest', suggested by Herbert Spencer, did not appear until the fifth edition of *Origin of Species* (1869) and is present 16 times in the sixth edition of *Origin of Species* (1872). The defining use of 'survival of the fittest' occurs in the second paragraph of Chapter III, Struggle for Existence (page 49), of the sixth edition and is reproduced in Box 6 along with two other relevant extracts. Box 6 derives from Appendix Table A5 which aligns all mentions of the phrase in the sixth edition with the corresponding entries in the fourth edition.

Box 6. Excerpts from *The Origin of Species by Means Of Natural Selection, Or The Preservation Of Favoured Races In The Struggle For Life* (Sixth Edition) that capture the gist of natural selection theory without recourse to 'survival of the fittest'.

From Chapter III, Struggle for Existence – paragraph 2 – page 49

Owing to this struggle, variations, however slight, and from whatever cause proceeding, if they be in any degree profitable to the individuals of a species, in their infinitely complex relations to other organic beings and to their physical conditions of life will tend to the preservation of such individuals, and will generally be inherited by the offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive. I have called this principle, by which each slight variation, if useful, is preserved, by the term Natural Selection, in order to mark its relation to man's power of selection. *But the expression often used by Mr. Herbert Spencer of the Survival of the Fittest is more accurate, and is sometimes equally convenient.*

From Chapter XV, Recapitulation and Conclusion - page 411

The slightest advantage in certain individuals, at any age or during any season, over those with which they come into competition, or better adaptation in however slight a degree to the surrounding physical conditions, will, in the long run, turn the balance.

[50] *The Concise Oxford English Dictionary, Fifth Edition* (1964). Oxford University Press, London.

From Chapter XV, Recapitulation and Conclusion – page 429

It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us [factors acting around us]. These laws, taken in the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the conditions of life, and from use and disuse: a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows.

Except for the sentence mentioning Herbert Spencer's phrase, 'survival for the fittest', the second paragraph of Chapter III (Struggle for Existence), in the first edition of *Origin of Species* is exactly the same as that in the sixth edition. Spencer's contribution may have been a useful gambit for broadening the readership of *Origin of Species* at a past time and place. However, the phrase 'survival of the fittest' is superfluous and figures as a hazard for intelligibility within One Health and hazard to social cohesion. The adjectival noun 'fittest' expresses a superlative which could imply a single unique individual within a group of entities. The phrase restated as 'survival of the fit' would allow for more than one fit entity within a group and would thus cater for the essential element of variation and diversity (see section 3.3.2). Note that Darwin explained 'survival of the fittest' on page 157 of the sixth edition of *Origin of Species* as follows: 'natural selection acts by life and death,—by the survival of the fittest, and by the destruction of the less well-fitted individuals. Comparison with what was said in the fourth edition of *Origin of Species* shows that the phrase is unnecessary: 'As natural selection acts by life and death,—by the preservation of individuals with any favourable variation, and by the destruction of those with any unfavourable deviation of structure.'

3.4 Darwin's *Origin of Species* joins Wallace's *Darwinism* to provide the groundwork for natural selection theory.

The purpose of this section is to set out the essentials of the Theory of Evolution by Natural Selection as described by Darwin in *Origin of Species* (1859, 1872) and Wallace in *Darwinism* (1889) so that they can be refined according to contemporary knowledge and transformed into definitions or summations for the proposed ontology and its purpose as a user interface between evolutionary biology and One Health. The works of Wallace and Darwin act in tandem in this regard. Neither alone provides a satisfactory account of the Theory of Evolution by Natural Selection. Wallace wrote *Darwinism* thirty years after the first edition of *Origin of Species*. In it, Wallace addresses some objections made to the theory of evolution by natural selection and adds further evidence in support of the theory. In consequence, *Darwinism* clarifies some of the content in *Origin of Species* and assists in framing the ontology for natural selection theory. Chapter 15 in *Darwinism* (Darwinism Applied to Man), like Darwin's *Descent of Man in Relation to Sex*, is deemed irrelevant to the present endeavour.

3.4.1 Preliminary considerations

The first three sentences in the extract from page 49 of *Origin of Species, Sixth Edition* (see Box 6 in section 3.2.7) describe the causal process that constitutes natural selection as a process that leads to the phenomenon of descent with modification or evolution. They are put forward as the best synopsis of the theory of evolution by natural selection found within *Origin of Species*, given limits to expression imposed by the biological knowledge available at the time of writing and the need to fill a void with figurative language. When supplemented with statements from pages 411 and 429 of *Origin of Species* (see Box 6; section 3.3.7), these sentences contain all ingredients necessary for a renewal of the theory of evolution by natural selection. The ingredients, factors, elements or causes[51] involved in 'descent with modification', which was Darwin's original name for 'evolution', are variation, inheritance (as 'implied by reproduction') and then selection. These factors are alluded to in the Darwin-Wallace papers delivered by others to the Linnaean Society of London in 1858[52] and are spelled out more comprehensively in *Origin of Species*. Note that selection goes together with its opposite; namely, rejection or elimination (see Maynard Smith, 1993). Selection acts upon and through the capabilities or characteristics that allow for organismal life or the continued existence of sub-organismal entities in the face of changing physical environments. A presupposition guiding the present review is that these characteristics and capabilities are perceivable.

A present-day view of natural selection comes from a blending of contemporary biology and words Darwin used in *Origin of Species*. It is at odds with Darwin's framing of sexual selection as a process separate from natural selection in both *Origin of Species* and *Descent of Man, and Selection in Relation to Sex* (1874). Section 3.4.4 elaborates on this particular issue. In short, sexual selection operates as a behaviour or characteristic within a species and will be subject to the 'direct action of the conditions of life' as are all other behaviours or characteristics. Natural selection is conceptually superordinate to sexual selection.

Wallace (1889) emphasises the pre-eminence of natural selection in Darwin's 'descent with modification' and explains in detail that sexual characters (including colourations and male rivalries) are the result of natural selection and not an alternative to natural selection. In doing so, Wallace establishes natural selection as the crux of evolution and confirms his indispensability as the co-author of Natural Selection Theory. An extract from the Preface of *Darwinism* (Wallace, 1889) makes his view of natural selection plain:

> 'Although I maintain, and even enforce, my differences from some of Darwin's views, my whole work tends forcibly to illustrate the overwhelming importance of Natural Selection over all other agencies in the production of new species. I thus take up Darwin's earlier position, from which he somewhat receded in the later editions of his works, on account of criticisms and objections which I have endeavoured to show are unsound. Even in rejecting that phase of sexual selection depending

[51]The word 'cause' can mean anything producing an effect or result. Causes are used as explanations of effects or results.

[52]See references: Darwin CR and Wallace AR (1858).

> on female choice, I insist on the greater efficacy of natural selection. This is pre-eminently the Darwinian doctrine, and I therefore claim for my book the position of being the advocate of pure Darwinism.'

The three factors of (1) inheritance coupled with reproduction, (2) variation and (3) selection classify as observable phenomena or things to be explained (see *explananda,* section 4.1.2). They are thus open to explanation and re-explanation (see *explanantia*, section 4.1.2) in the light of advancing knowledge rather than as conjectural and open to science's practice of refutation and falsification (Popper, 1963). In fact, the very notion of a phenomenon as a fact or observable occurrence such as gravity puts phenomena outside the scope of refutation or falsification. Explanations, however, are open to refutation. The verb 'renew' is apt for the present endeavour of re-explaining the theory of evolution by natural selection in the sense of Theory A (Science) and for the purposes of One Health. Renew and renewal refer to repairing, re-equipping or resupplying and can extend to the action of re-explaining the central elements of natural selection theory. The words 'refit', 'restore', 'regenerate' or 'overhaul' could also apply.

3.4.2 The phrase 'survival of the fittest' is not fit for purpose

The phrase 'survival of the fittest' in the last sentence of the extract from page 49 of *Origin of Species, Sixth Edition* expresses the outcome of natural selection as a process and does not describe the process of natural selection itself. Clear distinctions among processes, outcomes and other concepts is central to the present reformulation of the theory of evolution by natural selection. Ambiguities within the phrase 'survival of the fittest' allowed its misuse within Social Darwinism and so-called 'Scientific Humanism' during the nineteenth and twentieth century (Hofstadter, 1955; Weindling, 2012). Table 15 in Appendix 2 shows that 'fit' can refer to 'worthy' as in having social or moral value. At the same time, the phrase 'survival of the fittest' clearly means that natural selection acts on individual organisms via their 'infinitely complex relations to other organic beings and to their physical conditions of life'.

Spencer, who promoted the phrase 'survival of the fittest' as the embodiment of evolution has a record of using 'fit' in the sense of social or moral worth or merit[53]. It is conceivable that Darwin was unaware of this equivocal usage and did not envisage possible future misconstructions of the phrase[54]. Darwin, nevertheless, welcomed the inclusion of 'survival of the fittest' in *Origin of Species* because he was concerned that his term 'natural selection' could imply 'conscious choice' (see Volume 1, *The Variation of Animals and Plants under Domestication: Darwin,* 1875)[55].

[53]Spencer used the word 'fittest' in the sense of 'most worthy' many times in a polemical essay titled 'Representative Government – What is it good for?' which was published in 1857 (Spencer, 1891). The following excerpt is a sample example: '*Representative government, then, cannot be called a success in so far as the choice of men is concerned. Those it puts in power are the fittest neither in respect of their interests, nor their culture, nor their wisdom'*.

[54]Laland and Brown (2002) have suggested that Social Darwinism could be more accurately named as Social Spencerism.

[55]From page 6 in *The Variation in Animals and Plants under Domestication, Volume 1* (Darwin (1875): 'This preservation, during the battle for life, of varieties which possess any advantage in structure, constitution, or instinct, I have called Natural Selection; and Mr. Herbert Spencer has well expressed the same idea by the Survival of the Fittest. The term "natural selection" is in some respects a bad one, as it seems to imply conscious choice; but this will be disregarded after a little familiarity. No one objects to chemists

Furthermore, Darwin makes it clear in *The Descent of Man and Selection in Relation to Sex* (Darwin, 1882) that his interpretation of 'survival of the fittest' was not meant to apply to social or moral worth or merit in *Homo sapiens*[56].

The phrase 'survival of the fittest' is reckoned as captious and misleading and thus irrelevant and possibly detrimental to the present consideration of natural selection theory. This stance is supported by the following comments by Sober (2006):

> 'Herbert Spencer coined the slogan ''survival of the fittest'' to describe Darwin's theory and Darwin adopted this description phrase, thinking that it might help readers avoid misunderstanding what he mean by his own term, ''natural selection.'' Had he realized the confusions that would ensue, maybe Darwin would have distanced himself from this slogan. For once the theory is summarized by the phrase ''the survival of the fittest,'' it invites the following line of criticism: Who survives? Those who are fit. And who are the fit? Those who survive. If the theory of natural selection comes to no more than this, then the ''theory'' is no theory at all. It is a piece of circular reasoning, an empty truism, which masquerades as a substantive explanation of what we observe.'

Significantly, the first sentence in the extract from the last paragraph of *Origin of Species* (Chapter XV, Recapitulation and Conclusion – page 429) indicates that the result of natural selection applies to all levels of biological organisation: 'these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us', restated as factors acting around us to account for the current meaning of laws in science. The concept of biological organisation as a system with levels from the cell downwards to sub-cellular entities and from the cell upwards through populations, ecosystems and beyond (see Odum, 1983) may not have been available to Darwin and Wallace.

The phrase 'survival of the fittest' should be rejected and replaced by phrases that convey the same meaning but without the accompanying ambiguities and scope for misanthropic eugenics and social Darwinism. The word 'fittest' is a superlative and could imply a self-defeating reduction in variation that impedes evolution. 'Fit' would have sufficed. Possible examples of apt replacements for 'survival of the fittest' are (1) survival of the fitter, (2) survival of the fit, (3) survival of the fitted, (4) survival of the suitable, (5) survival of the suited, (6) survival of the viable, (7) survival of the capable, (8) survival of the able and (9) survival of the adapted.

3.4.3 Inheritance, reproduction and variation

Maynard Smith (1993) lists the three pillars of evolution as inheritance, reproduction and variation and the concluding paragraph of *Origin of Species* attests to the importance these factors in

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speaking of "elective affinity;" and certainly an acid has no more choice in combining with a base, than the conditions of life have in determining whether or not a new form be selected or preserved'.

[56]From page 61 of Darwin's *The Descent of Man, Second Edition*, 1882: 'Therefore, it hardly seems probable, that the number of men gifted with such virtues, or that the standard of their excellence, could be increased through natural selection, that is, by the survival of the fittest; for we are not here speaking of one tribe being victorious over another'.

evolution or ‘descent with modification’ when Darwin states that the life forms in the ‘tangled bank’ ‘have all been produced by laws acting around us’ (reworded in the present work as factors acting around us) and that ‘these laws, taken in the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction’ and ‘variability from the indirect and direct action of the conditions of life, and from use and disuse (usefulness, section 3.4.1)’.

Reproduction, means making a copy, or a likeness, and thereby providing for the continued existence of a species and the copy extends to a life form’s entire cycle of growth and development. Reproduction proceeds through all levels of biological organisation starting with the replication of informational macromolecules (RNA and DNA), followed by the individual sub-organismal or organismal life form and transmitting to populations, communities and ecosystems (Bonner, 2009). Growth and reproduction are intimately entwined.

Meanings of inherit and inheritance their functional bond with reproduction empower an understanding of the theory of evolution by natural selection. The word ‘inheritance’ is found 70 times within *Origin of Species, Sixth Edition* and the word ‘inherit’ appears 181 times. Advances in evolutionary biology have been accompanied by a profusion of words related to or built upon the notion of ‘inheritance’; for example ‘gene’ and ‘genetics’. To assist towards the universal intelligibility of natural selection theory, Box 7 lays out a hypothetical thesaurus entry or semantic field around the keyword of ‘inheritance’. Technical words are accompanied by definitions taken from a textbook of genetics (Passarge, 2007). These definitions are referenced to their origin and provide a standard for possible drifts of meaning or possibly improved clarity within the bewildering diversity of definitions found in textbooks. Dictionary definitions of inherit and inheritance provide a sound foundation for understanding the derived concepts shown in Box 7. For World English (Rooney, 1999), these definitions are:

> Inherit: *Receive a characteristic or quality from a parent*; to receive a characteristic or quality as a result of it being passed on genetically.
> Inheritance: *Biol. Transmission of genetically controlled characteristics*; the transmission of genetically controlled characteristics from parent to offspring.

Box 7: A hypothetical thesaurus entry for keyword ‘inheritance’- noun only and selected definitions for accompanying concepts .

Ancestry,
Descent, inheritance, heredity, endowment, breeding, lineage, succession.
Genetics:
(Bateson, 1906)—the science of heredity and the hereditary basis of organisms; derived from Gk. *genesis* (origin)**.**
Definitions from Passarge (2007)

> **Gene:** (Johannson, 1909) — hereditary factor that constitutes a single unit of hereditary material. It corresponds to a segment of DNA that codes for the synthesis of a single polypeptide chain (cf. Cistron).
> **Allele:** (Johannsen, 1909) or **allelomorph** (Bateson and Saunders, 1902)—one of several alternative forms of

a gene at a given gene locus.
Gene locus: (Morgan, Sturtevant, Muller, Bridges, 1915)—the position of a gene on a chromosome.
Genome: (Winkler, 1920)—all of the genetic material of a cell or of an individual.
Genotype: (Johannsen, 1909)—all or a particular part of the genetic constitution of an individual or a cell (cf. phenotype).
Phenotype (Johannsen, 1909)—the observable effect of one or more genes on an individual or a cell.
Heritability (Lush, 1950; Falconer, 1960)—the ratio of additive genetic variance to the total phenotypic variance. Phenotypic variance is the result of the interaction of genetic and nongenetic factors in a population.
Penetrance (Vogt, 1926)—the frequency or probability of expression of an allele (cf. expressivity)
Expressivity (Vogt, 1926)—refers to the degree of phenotypic expression of a gene or genotype. Absence of expressivity is also called nonpenetrance.
Epigenetics: the study of genetic effects on the phenotype not caused by alteration of the DNA sequence. [**epigenetic:** a heritable effect on gene or chromosomes function that is not accompanied by a change in the DNA sequence].
Epistasis (Bateson, 1907)—nonreciprocal interaction of genes at the same gene locus (allelic) or at different gene loci (nonallelic) that alter the phenotypic expression of a gen

It is a fact of history that the theory of evolution by natural selection was proposed at a time when the processes and mechanisms for inheritance were unclear (Ridley, 2004). This knowledge deficit is not critical because the phenomenon of inheritance joins the phenomena of variation and selection as overarching principles for natural selection theory. The capability and functions for inheritance and not the mechanism of inheritance determines the cogency of natural selection theory. In this regard, the usual lexical distinction between function as the normal or characteristic action of anything and mechanism as a means of doing something operates for lucidity in the practice of biology and is indispensable to the management of disease and ill-health[57]. Phenomenon (that which is observed) is the overarching or superordinate concept and mechanisms (the entities and activities organised in such a way that they are responsible for the phenomenon) fall underneath as subordinate concepts. Knowledge of the processes and mechanisms involved in inheritance springs from primary observations of the phenomenon of inheritance in nature. Primary observations of phenomena guide and motivate investigations into mechanisms that can result in new insights with practical application in One Health.

Darwin's two volumes on *The Variation of Animals and Plants Under Domestication* (Darwin, 1875) make it clear that nineteenth century knowledge of the phenomenon of inheritance provided a sound basis for the theory of evolution by natural selection and a good starting point for subsequent elucidation of the processes and mechanisms involved. Darwin's account of selective breeding extended to both benefits and harms and the realities he recounts could have forestalled subsequent claims that (1) a so-called blending mechanism for inheritance undermined theory of evolution by natural selection or (2) that Darwin himself had any view whatsoever about blending inheritance[58].

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[57] In plain words, a function is what something does and a mechanism is the way that it does it. The signs and symptoms of disease and ill-health point to disordered functions and clinical reasoning searches out plausible pathophysiological mechanisms that suggest possible interventions (see Braunwald et al., 1987).

[58] The following quotation about Darwin and blending inheritance comes from '*The Genetical Theory of Natural Selection*' (R.A. Fisher, 1930). It demonstrates that some of the past and influential literature on evolution confuses phenomenon and mechanism and did not comprehend the crucial distinction: 'THAT Charles Darwin accepted the fusion or blending theory of inheritance, just as all men accept many of the undisputed beliefs of their time, is universally admitted . That his acceptance of this theory had an important influence on his views respecting variation, and consequently on the views developed by himself and others on the possible causes of organic evolution, was not, I think, apparent to himself, nor is it sufficiently appreciated in our own times'. This statement from

Darwin's two volumes on *The Variation of Animals and Plants Under Domestication* (Darwin, 1875) contain sufficient field observations on inheritance to refute the possibility of blending inheritance.

All editions of *Origin of Species* record that Darwin's proposal for natural selection as the driver of descent with modification was inspired by the artificial selection applying to the selective breeding of plants and animals. This fact has vital implications for the present renewal of natural selection theory. Darwin used the word 'natural' as a convenience to distinguish natural selection from artificial selection and without reference to the three meanings of 'nature' and 'natural' as set out in Table 5. The processes of natural selection will necessarily apply to the selective breeding of plants and animals because this activity takes places in Nature C (that is, in the physical world including all natural phenomena and living things) and there will be exposure to Nature B (that is the forces controlling the physical world). The present renewal of the theory of evolution by natural selection will build from Nature A (Essence); that is, from the intrinsic or essential character of somebody or something. Natural selection will be explained more fully in section 3.3.4 as the outcome of interactions between the intrinsic or essential character of an organism and the intrinsic or essential character of the environment in which the organism lives.

Darwin's reference to 'variability from the indirect and direct action of the conditions of life, and from use and disuse' contains the phrases 'conditions of life' and 'use and disuse" which require explanation. A textual scan of *Origin of Species* reveals 132 mentions of 'conditions of life', five mentions of 'external conditions of life' and 11 mentions of 'conditions of existence'. The five mentions of 'external conditions of life' are instructive because they signal that Darwin envisaged 'conditions of life' that were either intrinsic or extrinsic to a life form. Darwin states that 'it would be a bold man who would account for the differences between a dray and race horse, a greyhound and bloodhound, a carrier and tumbler pigeon'...'according to the direct and definite action of the external conditions of life'. So, the 'conditions of life' that give rise to variability are factors within life forms that generate variants or 'an individual or species deviating in some character or characters from type' (Lawrence, 2008) and factors external to the life form that test the viability of a variant. A two-component structure of the 'conditions of life' accords with the proposed ontology for the theory of evolution by natural selection which sees natural selection as the result of interactions between the nature or intrinsic characteristics and properties of a life form and those of their environment. These interactions are expounded in the next section.

A textual scan of *Origin of Species* identified four considerations of the phrase 'use and disuse'. In the introductory historical sketch, Darwin states that Lamarck (Jean-Baptiste Pierre Antoine de Monet, chevalier de Lamarck, b.1744, d. 1829), attributed the means of modification of a life form to three factors, which were the 'physical conditions of life', the 'crossing of already existing forms, and to 'use and disuse or the effects of habit'. In Chapter 5 on the 'Laws of Variation', Darwin concludes by saying that 'we may conclude that habit, or use and disuse (now described as usefulness, section 3.4.1) have, in some cases, played a considerable part in the modification of the

Fisher contains unsupported assertion.

constitution and structure; but that the effects have often been largely combined with, and sometimes overmastered by, the natural selection of innate variations'. In Chapter 7 on 'Miscellaneous Objections to the Theory of Natural Selection', Darwin refers to Mivart's[59] lack of attention to the concept of 'use and disuse' and states that variability is governed by 'the many complex laws' that constitute natural selection including 'the increased use and disuse of parts, and the definite action of the surrounding conditions'. The last Chapter of *Origin of Species*, 'Recapitulation and Conclusion' contains five considerations of 'use and disuse', all of which equate to the phenomenon of usefulness. To explain, The noun 'use', referring to the state of being used, and the noun 'disuse', referring to the state of 'not being used' amalgamate into the noun 'usefulness', which refers to the quality or fact of being useful. Usefulness as a phenomenon is entailed in the capabilities that make for life (see Glossary) and will substitute for 'use and disuse' in the proposed ontology for evolution theory. Connotations of the phrase 'use and disuse' that imply cause are set aside.

In summary, inheritance (as 'implied by reproduction'), variation and selection were firm factual pillars for the theory of evolution by natural selection at its inception and they remain so today. These pillars have been illuminated and not displaced by advances in an understanding of the processes and mechanisms that underpin them. One present concern is that some of the terms invented for processes and mechanisms applying to inheritance may blur an understanding of the theory of evolution by natural selection because they are *'plagued in their usage by multiple concurrent and historically varying meanings'* (Keller and Lloyd, 1992). With this in mind, Table 6 expands on the notion of 'descent with modification' and an extract from the last paragraph of *Origin of Species* by adding dictionary definitions of words as set out in Table 3. The exposition of detail in Table 6 may assist in translations of the theory of evolution by natural selection from World English to other languages.

Table 6: Salient excerpts from *Origin of Species* with definitions of key words that clarify the phrase 'descent with modification'.

Salient excerpts from *Origin of Species*	**Augmentation of salient excerpts with definitions of key words**
Header: Descent with modification	Definition • Descent [*the fact of descending or being descended from an ancestor or ancestral stock, lineage*] • with modification [*CHANGE a slight change or alteration made to improve sth or make it more suitable*].
Specific phrases • These laws, taken in the largest sense, being Growth with Reproduction; • Inheritance which is almost implied by reproduction; • Variability from the	Definitions • These laws, taken in the largest sense, being Growth with Reproduction [*The process of producing new individuals of the same species by some form of generation: the generative production of new animal or vegetable organisms by or from existing ones; also, the power of reproducing in this way* OR *Reproduction is a fundamental property of protoplasm by which organisms give rise to organisms of the same kind*.].; • Inheritance [*Natural derivation of qualities or characters from*

[59]St. George Jackson Mivart (30 November 1827 – 1 April 1900), author of 'On the Genesis of Species' (1871); https://www.gutenberg.org/ebooks/20818.

indirect and direct action of the conditions of life, and from use and disuse: • a Ratio of Increase so high as to lead to a Struggle for Life, • and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less improved forms.	*parents or ancestry- any property, quality or immaterial possession inherited from ancestors or previous generations* OR *the acquisition of of characteristics by transmission of germ plasm from ancestor to descendant*], which is almost implied by reproduction; • Variability from the indirect and direct action of the conditions of life, and from use and disuse: a Ratio of Increase so high as to lead to a Struggle for Life [In literal as opposed to figurative language this refers to the demonstration of viability or being viable: i.e. *Capable of living, able to maintain a separate existence* OR *Capable of living' and 'workable and likely to survive or have real meaning, pertinence etc*] • and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less improved forms [Natural here refers to Nature B (Forces): *FORCES CONTROLLING THE PHYSICAL WORLD; The forces and processes collectively that control the phenomena of the physical world independently of human volition or intervention.*

3.4.4 Selection as in natural selection

Keller and Lloyd (1992) point out that natural selection is among the terms in evolutionary biology plagued by semantic confusion (see section 2.7). In addition, textbooks on evolutionary biology tend to define natural selection in terms of outcomes of a process and do not necessarily give the gist of the process itself. Beyond this, natural selection as the key to the theory of evolution by natural selection has been confused by arguments that other forms of selection, such as sexual selection or genie selection (Williams, 1966), exist in the natural world. This confusion has a root cause in Darwin's internally inconsistent proposition that sexual selection is a process separate from natural selection, which is developed in his book *The Descent of Man: and Selection in Relation to Sex* (1874). Wallace (1889) reaffirms the ascendancy of natural selection and that selection involving sexual characteristics is part of natural selection (see section 3.3.1). This view is endorsed by the depiction of natural selection as a passive filter (Noble, 2021), which echoes the suggestion that evolutionary thinking in engineering and general science may be enhanced through the concept of viability and elimination rather than that of competition and selection (Maesani et al., 2014)

Confusion around the term 'natural selection' is a major impediment to progress. Accordingly, the following three-step method seeks for a crisp, intelligible and operationally effective account of natural selection that will guide the translation of the theory of evolution by natural selection for use in One Health.

- First step: *Origin of Species* will be scoured for passages that demonstrate what Darwin originally meant by natural selection and the results will be supplemented with commentaries.
- Second step: Darwin's use of knowledge from animal and plant breeding to construct the theory of evolution by natural selection will be repeated. Some current textbooks on animal breeding (Bourdon, 2014; Oldenbroek and van der Waaij, 2014) and on genetics relevant to

animal disease and animal production (Nicholas, 1996) will be drawn upon for their perspective on terms shared with evolutionary biology.

- Third step: Findings from the second step will be matched against definitions of natural selection from a sample of books on evolutionary biology, zoology and botany. The outcome of this third and last step will be used as the version of selection in the proposed ontology for the theory of evolution by natural selection (see section 5).

Step 1 towards a precising definition of natural selection – what Darwin said

Some passages from *Origin of Species* that capture what Darwin meant by natural selection are presented in Box 8.

Box 8: Some excerpts from *Origin of Species* that convey the gist of evolution as a process

The full title itself: The Origin of Species by Means of Natural Selection, *or the preservation of favoured races in the struggle for life.*

Pages 3-4: As many more individuals of each species are born than can possibly survive; and as, consequently, there is a frequently recurring struggle for existence, *it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be naturally selected.* From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form.

From page 49: *Owing to this struggle, variations, however slight, and from whatever cause proceeding, if they be in any degree profitable to the individuals of a species, in their infinitely complex relations to other organic beings and to their physical conditions of life, will tend to the preservation of such individuals, and will generally be inherited by the offspring. The offspring, also, will thus have a better chance of surviving,* for, of the many individuals of any species which are periodically born, but a small number can survive. I have called this principle, by which each slight variation, if useful, is preserved, by the term Natural Selection, in order to mark its relation to man's power of selection.

But the expression often used by Mr. Herbert Spencer of the Survival of the Fittest is more accurate, and is sometimes equally convenient.

From page 63: Several writers have misapprehended or objected to the term Natural Selection. Some have even imagined that natural selection induces variability, *whereas it implies only the preservation of such variations as arise and are beneficial to the being under its conditions of life.* No one objects to agriculturists speaking of the potent effects of man's selection; and in this case the individual differences given by nature, which man for some object selects, must of necessity first occur. Others have objected that the term selection implies conscious choice in the animals which become modified; and it has even been urged that, as plants have no volition, natural selection is not applicable to them! *In the literal sense of the word, no doubt, natural selection is a false term; but who ever objected to chemists speaking of the elective affinities of the various elements?—and yet an acid cannot strictly be said to elect the base with which it in preference combines.* It has been said that I speak of natural selection as an active power or Deity; but who objects to an author speaking of the attraction of gravity as ruling the movements of the planets?

From page 85: Slow though the process of selection may be, if feeble man can do much by artificial selection, *I can see no limit to the amount of change, to the beauty and complexity of the coadaptations between all organic beings, one with another and with their physical conditions of life, which may have been effected in the long course of time through nature's power of selection,* that is by the survival of the fittest.

From pages 102-103: *But if variations useful to any organic being ever do occur, assuredly individuals thus*

characterised will have the best chance of being preserved in the struggle for life; and from the strong principle of inheritance, these will tend to produce offspring similarly characterised. This principle of preservation, or the survival of the fittest, I have called Natural Selection. **From page 165**: Although the belief that an organ so perfect as the eye could have been formed by natural selection, is enough to stagger any one; yet in the case of any organ, *if we know of a long series of gradations in complexity, each good for its possessor, then, under changing conditions of life, there is no logical impossibility in the acquirement of any conceivable degree of perfection through natural selection.* **From page 412:** If man can by patience select variations useful to him, why, under changing and complex conditions of life, should not variations useful to nature's living products often arise, and be preserved or selected? What limit can be put to this power, acting during long ages and rigidly scrutinising the whole constitution, structure, and habits of each creature,—favouring the good and rejecting the bad? *I can see no limit to this power, in slowly and beautifully adapting each form to the most complex relations of life. The theory of natural selection, even if we look no farther than this seems to be in the highest degree probable.*

According to the extracts in Box 8, Darwin put forward a simple and clear view of natural selection as the survival and propagation of those variants of a species able to deal with their conditions of life or to function effectively within a given environment. The word ‘species’ in Box 8 has the simple meaning of a kind or sort of thing (see Appendix Table A2). Darwin’s reference to chemistry and acid-base reactions makes it clear that natural refers to Nature B (Forces): the forces and processes collectively that control the phenomena of the physical world independently of human volition or intervention. Darwin corrects any impression that he views selection as operating through an active power or Deity. Darwin also corrects the misapprehension that natural selection induces variation.

Darwin’s depiction of natural selection becomes muddied when he discusses sexual selection according to the following extract from page 69 of *Origin of Species (Sixth Edition)*: ‘This leads me to say a few words on what I have called Sexual Selection. This form of selection depends, not on a struggle for existence in relation to other organic beings or to external conditions, but on a struggle between the individuals of one sex, generally the males, for the possession of the other sex. The result is not death to the unsuccessful competitor, but few or no offspring. Sexual selection is, therefore, less rigorous than natural selection’. Interestingly, sexual selection is mentioned only once in the final Chapter (Recapitulation and Conclusion) of the book and is omitted from the memorable last page. For present purposes, Darwin’s distinction between sexual and natural selection is dismissed unreservedly for its clear inconsistency with what is said on page 49 and the words used the last paragraph. His separation of the two does not recognise natural selection as an overarching whole that encompasses sexual selection. Wallace (1889) insists upon the ‘overwhelming importance’ of natural selection in his preface to *Darwinism* and thus counteracts the mistaken view of sexual selection in *Origin of Species.*

Darwin continues his paradoxical and views about sexual selection and other matters in his book *The Descent of Man and Selection in Relation to Sex* (1871, 1874 and 1889), where he demonstrates

an uncritical acceptance of some harmful social norms of the time. He described indigenous Americans and Australians as inferior to Europeans in capacity and behaviour. His experience with indigenous Australians was fleeting and would give no evidence base for such a view. Brown (2021) provides a sympathetic but realistic view of Darwin as a human being with strengths and weaknesses and a person who had imbibed the presumptions, prejudices and vanities of his time and place.

Step 2 towards a precising definition of natural selection – animal breeding

The second step towards clarifying natural selection for use in the proposed ontology for the theory of evolution by natural selection involves the terminology around selection used in the breeding of domestic animals. Box 9 contains extracts from two textbooks on animal breeding (Bourdon, 2014; Oldenbroek and van der Waaij, 2014) and another on genetics tailored to veterinary needs (Nicholas, 1996). The intent is to follow the example of Darwin and draw parallels between the selective breeding of animals (artificial selection) and natural selection. This second step is essentials for a present-day interpretation of what Wallace and Darwin implied by selection.

Box 9: Terminology around selection used in selected textbooks on animal breeding and genetics

Bourdon (2014)

Population: A group of intermating individuals. The term can refer to a breed, an entire species, a single herd or flock, or even a small group of animals within a herd.
Selection: The process that determines which individuals become parents, how many offspring they produce, and how long they remain in the breeding population: The method used by breeders to make long-term genetic change in animals.
Replacement Selection: The process that determines which individuals will become parents for the first time.
Culling: The process that determines which parents will no longer remain parents.
Trait: Any observable or measurable characteristic of an individual. [When we describe animals, we usually characterize them either in terms of appearance or performance or some combination of both. In any case, we talk about traits]
Phenotype: An observed category or measured level of performance for a trait in an individual. [We often use the word performance instead of phenotype for traits that are measured rather than observed with the eye. In this book, I use the terms phenotype and performance interchangeably.]
Performance testing: Systematic measurement of performance (phenotype) in a population.
Genotype: The genetic makeup of an individual.
Breeding Value: The value of an individual as a (genetic) parent.
Phenotypic Selection: Selection based solely on an individual's own phenotype(s).
Heritability: A measure of the strength of the relationship between breeding values and phenotypic values for a trait in a population.
Fitness: The ability of an individual and its corresponding phenotype and genotype to contribute offspring to the next generation. The term refers to the number of offspring an individual produces—not just its ability to be selected.

Oldenbroek and Waaij (2014)

Trait: A distinguishing phenotypic characteristic, typically belonging to an individual. In practice this means anything you can record or measure on an individual.
Phenotype: What you observe or measure on the animal for a certain trait. It can depend both on the genetic background of the animal (provided it is heritable) and external circumstances such as level of nutrition. A phenotype

is the observed value of a trait. It is a consequence of all the genetic and environmental influences and interactions affecting the trait, including errors in measurements.
Animal breeding: The selective breeding (in other words artificial selection) of domestic animals with the intention to improve desirable (and heritable) qualities in the next generation.
Natural selection: The process whereby animals that are better adapted to their environment have a higher chance to survive and produce more offspring than less adapted animals. The next generation thus, on average, will be more adapted than the current generation.
Artificial selection: '*It sounds as if animal breeding is all in the hands of the humans. Compared to natural populations this indeed is the case, as we decide which animals are allowed offspring and which are not: selective breeding or in other words artificial selection. However, as in natural populations there is another force that plays an important role and that is the force of natural selection. In natural selection it is not us but the environment that determines survival and reproductive success of animals. So after we have decided which animals we intend as parents, they still need to be able to survive until reproductive age and to be able to reproduce successfully*'.
Adaptive fitness: Characterized by survival, health and reproduction related traits. In the warmer tropical areas, pathogens and epidemic diseases are widespread, climatic conditions are stressful, and feed and water are scarce. There, locally adapted autochthonous breeds display a far greater level of resistance and adaptation due to their evolutionary roots as compared to imported breeds.
Breed: An interbreeding group of animals within a species with some identifiable common appearance, performance, ancestry or selection history. Many definitions are used to define this concept. 'A breed is a breed if enough people say it is' (K. Hammond, personal communication).
Species: The largest group of animals that are capable of interbreeding and producing fertile offspring.
Environment: anything that influences the animal's performance that is not related to the genetic makeup of the animal, starting at the earliest possible moment in life, even before conception.

Nicholas (1995)

Genotype: The genetical composition of an individual at one or more loci (i.e.particular sites of genes on chromosomes).
Phenotype: Refers to an observable trait of an individual.
Selection: Acts on phenotypes and occurs whenever some phenotypes have a greater opportunity to contribute offspring to to the next generation than do other phenotypes. Selection may act at any stage during the life cycle of an animal from conception to mating. Selection most commonly occurs through differential viability and/or differential reproductive ability, with reproductive ability including factors such as mating ability, fecundity and fertility.
Artificial selection: refers to selection occurring as a result of decisions made by humans. Selection in all other circumstances is natural selection and the principles by which selection occurs are exactly the same. Selection acts on phenotypes but has a consequent effect on genotypes and gene frequencies BUT selection really acts only on individual animals according to their phenotype.
Fitness: Seen as the combined effect of viability and reproductive ability (Note: The full notion of viability did not have currency when *Origin of Species* was written).

Oldenbroek and Waaij (2014) emphasise that organisms selected by people are also exposed to natural selection. The extensive list of disorders and diseases in animals caused by the inheritance of undesirable characters (see website Online Mendelian inheritance in Animals, www.omia.org) argues for an understanding of the theory of evolution by natural selection that can underpin quality management in animal breeding.

Step 3 towards a precising definition of natural selection – textbooks on evolutionary biology

Table 7 contains a sample of definitions of natural selection from textbooks on evolutionary biology which can be matched against those found in textbooks of animal breeding and veterinary genetics.

Table 7: Definitions of of natural selection from selected textbooks on evolutionary biology, zoology and botany.

	Source	Definition
1,	Abercrombie M, Hickman CJ and Johnson ML (1957) *A Dictionary of Biology.* Penguin Books, Harmondsworth.	The definition given is lengthy and convoluted. Two extracts have been selected to convey the general meaning. 1. 'The theory that evolution occurs by natural selection asserts that, of the range of different individuals which make up the population of a given species, those individuals having certain characteristics contribute more offspring to the succeeding generation than those having other characteristics; and if such characteristics have an inherited basis, the composition of the population is thereby changed………………' 2. 'In other words different variations (q.v.) have different "survival" value in the face of the hostile circumstances in which all organisms live.'
2.	Raven PH, Evert RF and Eichhorn SE (1992) *Biology of Plants, Fifth Edition*. Worth Publishers, New York.	The differential production of genotypes based on their genetic constitution.
3.	Endler JA (1992) Evolution. In: *Keywords in Evolutionary Biology* (Edited by Keller EF and Lloyd EA). Harvard University Press, Harvard, Massachusetts.	NATURAL SELECTION can be defined as a process that occurs if and only if these three conditions are present: the population has a) variation among individuals in some attribute or trait (phenotypic variation): (b) a consistent relationship between that trait and mating ability, fertilizing ability, fertility, fecundity, and/or survivorship (fitness variation) and (c) a consistent relationship, for that trait, between parents and their offspring, which is at least partially independent of common environment effects (inheritance). If these three conditions are met, then one or both outcomes will occur: (1) the trait frequency distribution will differ among age classes or life-history stages to an extent beyond that expected from ontogeny (growth and development); (2) if the population is not at equilibrium, then the trait distribution of all offspring in the population will be predictably different from that of all parents, beyond that expected from conditions (a) and (c) alone.
4.	National Academy of Sciences, Working Group on Teaching Evolution, (1998) *Teaching About Evolution* and *the Nature of Science*. National Academies Press, Washington DC.	Greater reproductive success among particular members of a species arising from genetically determined characteristics that confer an advantage in a particular environment.
5.	Freeman S and Herron SC (2001) *Evolutionary Analysis, Second Edition.* Prentice Hall, Upper Saddle River, New Jersey.	A difference, on average, between the survival or fecundity of individuals with certain phenotypes compared to individuals with other phenotypes.
6.	Hickman CP et al (2006) *Integrated Principles of Zoology, Thirteenth Edition*.	A nonrandom reproduction of varying organisms in a population that results in the survival of those best adapted to their environment and elimination of those less well

	Source	Definition
	McGraw Hill, New York.	adapted, leads to evolutionary change if the variation is heritable.
7.	Mayr E (2001) *What Evolution Is*. Basic Books, New York.	The process by which in every generation individuals of lower fitness are removed from the population.
8.	Campbell NA and Reece JB (2002) *Biology, Sixth Edition.* Benjamin Cummings, San Francisco.	Differential success in the reproduction of different phenotypes resulting from the interaction of organisms with their environment. Evolution occurs when natural selection causes changes in relative frequencies of alleles in the gene pool.
9.	Ridley M (2004) *Evolution, Third Edition*. Blackwell Publishing Company, Oxford.	The process by which the forms of organisms in a population that are best adapted to the environment increase in frequency relative to less well adapted forms over a number of generations.
10.	Hall and Hallgrimson (2007) *Strickberger's Evolution, Fourth Edition.*	Differential reproduction or survival of replicating organisms caused by agencies that are not directed by humans (see Artificial selection). Since such differential selective effects are widely prevalent, and often act on hereditary (genetic) variations, natural selection is a common major cause for a change in the gene frequencies of a population that leads to a new distinctive genetic constitution (evolution).
11.	National Academy of Sciences and Institute of Medicine of the National Academies (2008) *Science, Evolution, and Creationism.* National Academies Press, Washington, DC.	The process by which organisms with advantageous variations have greater reproductive success than other organisms within a population is known as 'natural selection'.
12.	Hine R (2010) *A Dictionary of Science.* Oxford University Press, Oxford.	The process that, according to *Darwinism, brings about the evolution of new species of animals and plants. Darwin noted that the size of any population tends to remain constant despite the fact that more offspring are produced than are needed to maintain it. He also saw that variations existed between individuals of the population and concluded that disease, competition, and other forces acting on the population eliminated those individuals less well adapted to their environment. The survivors would pass on any heritable advantageous characteristics (i.e. characteristics with survival value) to their offspring and in time the composition of the population would change in adaptation to a changing environment. Over a long period of time this process could give rise to organisms so different from the original population that new species are formed.
13.	Losos J (2014) What is evolution. In: *The Princeton Guide to Evolution* (Editor-in-Chief Losos JB). Princeton University Press, Princeton, New Jersey.	The process in which individuals with a particular trait tend to leave more offspring in the next generation than do individuals with a different trait.
14.	Futuyma D and Kirkpatrick M. (2017) Evolution, Fourth Edition. Sinauer Associates, Sunderland MA.	The differential survival and/or reproduction of classes of entities that differ in one or more characteristics. To constitute natural selection, the difference in survival and/ or reproduction cannot be due to chance, and it must have the potential consequence of altering the proportions of the different entities. Thus natural selection is also definable as

	Source	Definition
		a deterministic difference in the contribution of different classes of entities to subsequent generations. Usually the differences are inherited. The entities may be alleles, genotypes or subsets of genotypes, populations, or, in the broadest sense, species.

A precising definition of natural selection

The upshot of this protracted three-step process is an explicit and plain definition of natural selection that suits the proposed ontology for the theory of evolution by natural selection and its application within One Health. The definition in mind can encompass subordinate ideas like selection pressure, selection advantage, directional selection, stabilising selection and disruptive selection and other matters like kin selection and group selection. The word natural will operate in this plain definition according to its meaning as Nature A (Essence) or the inherent character or basic constitution of something. This meaning signifies that natural selection is a process involving interactions between the characteristics of the organism, virus or prion and the characteristics of the environment. Environment here simply refers to the external factors influencing the life of organisms and the existence of infectious agents like viruses and prions (see Appendix 2, Table 15). On this note, Darwin refers repeatedly in *Origin of Species* to the 'conditions of life' which is an apt way of describing the environment.

Darwin had no recourse to the notion of the environment and seems to have employed the word natural in either in the sense of Nature B (Forces) or the forces controlling the physical world, or Nature B (Physical World), which refers to the physical world itself. The challenge for Darwin was to differentiate natural selection from so-called artificial selection which referred to farming practices of selective breeding of plants and animals and inspired his thinking. Both occur under what he termed the 'conditions of life'.

The definition proposed by Ridley (2004) will serve as a starting point because it specifies selection as a process. Processes precede capabilities, functions and mechanisms in the ontology or web of concepts that will underpin the proposed conceptual framework for the theory of evolution by natural selection:

> 'Natural selection is the process by which the forms of organisms in a population that are best adapted to an environment increase in frequency relative to less well adapted forms over a number of generation*s'* (Ridley, 2004).

Nicholas (1995) makes it clear that selection acts on phenotypes and it doing so automatically involves the genetical composition of an individual. His description of selection, repeated below, sweeps away much of the conceptual confusion described by Keller and Lloyd (1992) and Laland and Brown (2002). It aligns with the distinction made by Mayr (1997 and 2001) between 'selection for' (the phenotype and its expressed capabilities) and 'selection of' (the genotype and its latent

possibilities). This distinction clarifies a crucial causal direction where 'selection for' must precede 'selection of' and which suits requirements for the ontology or web of concepts that will underpin the proposed ontology for Natural Selection Theory.

> 'Selection acts on phenotypes and occurs whenever some phenotypes have a greater opportunity to contribute offspring to the next generation than do other phenotypes. Selection may act at any stage during the life cycle of an animal from conception to mating. Selection most commonly acts through differential viability and/or differential reproductive ability, with reproductive ability including factors such as mating ability, fecundity and fertility' Nicholas (2001).

Noble (2021) provides a final word on natural selection: ' Charles Darwin (1859) introduced the idea of natural selection (a non-intentional filter) as a metaphorical comparison with artificial (intended) selection. There is no actual selection carried out by natural 'selection'. Nature – in this case the different rates of survival – is simply a passive filter. Yet it is often presented as the active driver of evolution'. The view of natural selection as a passive filter for viability will guide the proposed ontology for natural selection theory.

Perhaps 'selection through' can be added to Mayr's 'selection of' and 'selection for' and according to Noble's description of natural selection acting as a passive filter for viability (Maesani et al., 2014). The idea of 'selection through' may be elucidated by the example of selective breeding where 'selection of' is mediated by or selected 'through' an interested human agent according to observations and perceptions of appearance and performance. Selection 'through' the agency of a disinterested passive filter can apply to natural selection.

A precising definition of natural selection for the purposes of the proposed ontology is set out below.

> *Natural selection is the process that occurs when organisms or sub-cellular infectious agents such as viruses and prions interact with their environment according to their own nature, or intrinsic characteristics and properties, and the nature of their environment and its biotic and abiotic elements. Natural selection results in 'descent with modification' or generational change whereby forms of organisms or other life forms in a population that are better adapted to an environment increase in frequency relative to less well adapted forms. The process of natural selection works through a means likened to a passive filter where elimination and selection of phenotypes according to their viability is accompanied by elimination and selection for the associated genotypes.*

The precising definition of natural selection as the process producing Darwin's 'descent with modification' aligns with the concise summary of Darwin's main ideas provided by Campbell and Reece (2002). These are: (1) Natural selection is differential success in reproduction. (2) Natural selection occurs through an interaction between the environment and the variability inherent among the individual organisms [or other life forms] making up a population. (3) The product of natural selection is the adaptation of populations of organisms [or other life forms] to their environment.

The word ‘environment’ is not present in any edition of *Origin of Species* and Darwin employed the phrase ‘conditions of life’ to capture its meaning. Environment (‘conditions of life’) includes the biotic environment and associations between life forms and has implications for coevolution or the reciprocal evolutionary change between interacting species (Cavanaugh and Currie, 2014). Coevolution applies across the level-of-organisation spectrum from individual life forms to populations, communities and ecosystems (Odum, 1983). Coevolution is a necessary component in the renewal of the theory of evolution by natural selection for application in the One Health.

During the history of evolutionary biology the notion of selection has accompanied by discussions around so-called objects of selection which have been variously labeled as units of selection (Lewontin, 1970), replicators (Dawkins, 1978), or selectons (Mayr, 1997). Objects of selection are life forms that can evolve because they have three necessary capacities of variation, reproduction, and heritability (Lewontin, 1970; Hull, 1980). Given that selection acts through phenotypes (Nicholas, 1995) and operates at all level of biological organisation from genetic systems to ecosystems, units of selection can be seen as components of a ‘selection package’. Accordingly, ‘units of selection’ are intrinsic to the concept of selection and the notion will operate silently within the proposed ontology for the theory of evolution by natural selection.

<u>A precising definition of fitness</u>

The precising definition of fitness that suits the proposed ontology for the theory of evolution by natural selection is based on physiology because this discipline underpins the active participation required to deliver One Health. Other definitions of fitness and adaptation have been explored in the field of quantitative genetics (van der Werf et al., 2009). The three definitions of fitness described in books on animal breeding within step 2 can be combined with another from a textbook on evolutionary biology to form a definition that suits present purposes and which extends from organisms to sub-cellular infectious agents such as viruses and prions.

> **Fitness:** The ability of an individual and its corresponding phenotype and genotype to contribute offspring to the next generation. The term refers to the number of offspring an individual produces—not just its ability to be selected (Bourdon, 2014).
>
> **Adaptive fitness:** Characterized by survival, health and reproduction related traits. In the warmer tropical areas, pathogens and epidemic diseases are widespread, climatic conditions are stressful, and feed and water are scarce. There, locally adapted autochthonous breeds display a far greater level of resistance and adaptation due to their evolutionary roots as compared to imported breeds (Oldenbroek and Waaij, 2014).
>
> **Fitness:** Seen as the combined effect of viability and reproductive ability (Nicholas, 1995).
>
> **Fitness**: The success of an organism at surviving [that is, being viable] and reproducing and thus contributing offspring to future generations (Zimmer and Emlen, 2016).

The composite definition of fitness applicable to present purposes is '*success of an organism or a sub-cellular infectious agent, such as a virus or prion, at being viable and surviving and then contributing descendants to future generations'*.

As mentioned earlier (section 3.3.7), 'viable' or capable of life, did not have clear currency and a full breadth of meaning until the twentieth century.

3.4.5 Adaptation

The extract from page 411 of *Origin of Species* (1872) (see below) and page 103 of *Darwinism* (1889) demonstrate that Darwin and Wallace used the word 'adaptation' in reference to 'the state of being adapted or fitted' (Webster's Dictionary, 1828-1913) or 'the development of physical and behavioural characteristics that allow organisms to survive and reproduce in their habitats' (Encarta World English Dictionary, 1999).

> 'The slightest advantage in certain individuals, at any age or during any season, over those with which they come into competition, or better adaptation in however slight a degree to the surrounding physical conditions, will, in the long run, turn the balance'.
>
> 'We have seen that every species is exposed to numerous and varied dangers throughout its entire existence, and that it is only by means of the exact adaptation of its organisation—including its instincts and habits —to its surroundings that it is enabled to live till it produces offspring which may take its place when it ceases to exist'.

Subsequent obfuscation of the plain meaning of adaptation (Lewontin, 1957; Brandon, 1978) and perplexing debate around what is termed 'adaptationism' (Orzack and Sober, 2001; Orzack and Forber, 2017) is likely to have impeded wider use of evolutionary thinking within what is now known as One Health. Practitioners within One Health tend to operate from physiology where adaptation has straightforward meanings as a change in response to a stress of any kind (O'Toole, 2013) or a feature of form and function possessed by an organism that allows for existence in a particular environment. A selection of definitions for 'adaptation' is shown in Table 8 seeks for a meaning of the word that can guide action and inform the proposed ontology for the theory of evolution by natural selection. The sources are the same as those used for the definition of 'evolution' shown in Table 1.

Table 8: Selected definitions of the term 'adaptation'.

	Source	**Definition**
1,	Abercrombie M, Hickman CJ and Johnson ML (1957) *A Dictionary of Biology.* Penguin Books, Harmondsworth.	Any characteristic of living organisms which, in the environment they inhabit, improves their chances of survival and ultimately leaving descendants, in comparison with the chances of similar organisms without

	Source	Definition
		the characteristic.
3.	West-Eberhard MJ (1992) Adaptation, current usages. In: *Keywords in Evolutionary Biology* (Edited by Keller EF and Lloyd EA). Harvard University Press, Harvard, Massachusetts.	In contemporary evolutionary biology an 'adaptation' is a characteristic of an organism whose form is the result of selection in a particular functional context (see Williams, 1966; Futuyma, 1986). Accordingly, the process of 'adaptation' is the evolutionary modification of a character under selection for efficient or advantageous (fitness-enhancing) functioning in a particular context or set of contexts. The word is sometimes also applied to individual organisms to denote the 'propensity to survive and reproduce' in a particular environment (general adaptation) (see Mayr, 1988). Ernst Mayr (1986) suggests substituting the term 'adaptedness' for this usage.
5	Freeman S and Herron SC (2001) *Evolutionary Analysis, Second Edition.* Prentice Hall, Upper Saddle River, New Jersey.	A trait that increases the ability of an individual to survive or reproduce compared with individuals without the trait.
6.	Hickman CP, Roberts LS and Larson L (2001) *Integrated Principles of Zoology, Eleventh Edition*. McGraw Hill, New York.	Organic evolution encompasses all changes in the characteristics and diversity of life on earth throughout its history.
7.	Mayr E (2001) *What Evolution Is*. Basic Books, New York.	Any property of an organism believed to add to its fitness.
8.	Campbell NA and Reece JB (2002) *Biology, Sixth Edition.* Benjamin Cummings, San Francisco.	All the changes that have transformed life on Earth from its earliest beginnings to the diversity that characterizes it today.
9.	Ridley M (2004) *Evolution, Third Edition*. Blackwell Publishing Company, Oxford.	A feature of an organism enabling it to survive and reproduce in its natural environment better than if it lacked the feature
11.	*The Princeton Guide to Evolution* (Editor-in-Chief Losos JB). Princeton University Press, Princeton, New Jersey.	Mayer, GC: A feature of an organism that fits it to its conditions of existence, giving rise to similarity among organisms leading the same or similar ways of life. Wainwright, PC: A process of genetic change in a population whereby, as a result of natural selection, the average state of a character improves with reference to a specific function, or whereby a population is thought to have become better suited to some feature of its environment. Also, an adaptation: a feature that has become prevalent in a population because of a selective advantage conveyed by that feature in the improvement of some function. In this Chapter the term is used mostly in the latter sense—as a noun describing a trait that has evolved through this process and helps make the individuals in the population better suited to their habitat.
12.	Futuyma D and Kirkpatrick M. (2017) *Evolution, Fourth Edition.* Sinauer Associates, Sunderland MA.	A process of genetic change in a population whereby, as a result of natural selection, the average state of a character becomes improved with reference to a specific function, or whereby a population is thought to have become better suited to some feature of its environment. Also, an adaptation: a feature that has become prevalent

	Source	Definition
		in a population because of a selective advantage conveyed by that feature in the improvement in some function.
13.	Clugston MJ (2014) *The Penguin Dictionary of Science* Penguin Books, London.	Any characteristic that increases and organism's chance of survival in a given environment.
14.	McGraw-Hill Access Science (https://www.accessscience.com/content/article/a009800)	Adaptations are characteristic of an organism that make it fit for its environment and way of life.

Mayr (2001) uses the word adaptedness in a book that seeks to explain evolution. Context is contention around the so-called adaptationist program that occurred during the last part of the twentieth century (Gould and Lewontin, 1979; Mayr, 1983; Burian, 1992; West-Eberhard, 1992; Brandon 1996). Mayr (2001) states: 'Clearly, those individuals with characteristics providing the greatest adaptedness to the current circumstances have the greatest probability of survival'. 'Providing the greatest adaptedness' is another way of saying 'better adapted'. Mayr (2001) lists adaptation but not adaptedness in his glossary.

Another term, 'exaptation', requires attention. The term was coined by Gould and Vrba (1982) and is defined by Zimmer and Emlen (2016) as a trait that initially carries out one function and then carries out a new function: the original function may or may not be retained. In other words. adaptations for one function can be incipient adaptations for another function. The notion of exaptation is subordinate to the notion of adaptation and can merge beneath adaptation in the proposed ontology for natural selection theory.

In summary, three definitions of adaptation from Table 8 are listed in order their suitability for present purposes and then merged into a composite version. Present purposes relate to the ontology or web of concepts applying to the proposed ontology for natural selection theory. All definitions depict adaptation as a phenomenon with a role in viability. Organisms must survive in order to reproduce. The definition from Raven et al (1992) is favoured because it highlights structure, physiology and behaviour. Behaviour as an inherited property or feature is emphasised because it facilitates an understanding of associations within and between species and ecosystems (see section 4.2.2). Behaviour, or what things do and are seen to do, is a starting point for delivery of One Health.

> *A peculiarity of structure, physiology or behaviour that aids in fitting an organism to its environment (Raven et al., 1992).*
>
> *Any property of an organism believed to add to its fitness (Mayr, 2001).*[property includes behaviour]

> *An adaptation is a feature of an organism enabling it to survive and reproduce in its natural environment better than if it lacked the feature (Ridley, 2004).* [feature can include behaviour].

The composite and precising definition of an adaptation is shown below. It depicts adaptations as capabilities, which is important for the concept hierarchy in the ontology for the theory of evolution by natural selection where processes operate around capabilities and capabilities emerge from functions and mechanisms:

> *Any peculiarity, property or feature of the structure, physiology or behaviour of an organism or biological entity, such as a virus or prion, that enables it to be viable and to survive and reproduce in a particular environment.*

1. Adaptability is an extension on the term adaptation and refers to the extent to which any adaptation can adjust to prevailing circumstances. Thermal physiology in animals provides an example of the use of adaptability when it refers to thermo-neutral zones and summit heat production and heat loss that are beyond the capacity to cope (Moyes and Schulte, 2006) by means of homeostasis (Billman, 2020). Together, the terms adaptation and adaptability have a wide reach and encompass and explain concepts such as resilience, norm of reaction and disease.

Resilience refers to the capacity of living systems at various levels from individual life forms to communities and ecosystems to cope with and recover from the impact of perturbations or stressors (Crespi 2021, Thorogood et al., 2023). Resilience as the ability of a living system to restore itself to its original condition after being disturbed (Lawrence, 2008) runs in parallel with adaptability (see section 3.3.5) and depends upon processes for homeostasis (see section 4.3.4). Resilience also applies to ecosystems and the responsiveness to feedbacks that confer their stability (Odum, 1983). Resilience in the sense of recovery from the effects of adverse conditions couples with tolerance as the ability to withstand adverse conditions. The concept of resilience also illuminates the concepts of phenotypic plasticity and norm of reaction that have currency within evolutionary biology. Section 4.3.4a sums up reaction norms as the range of possible phenotypes from a given genotype and phenotypic plasticity as the range of possible life-sustaining capabilities from a given phenotype.

Notions of adaptation and adaptability also illuminate the concept of disease. Disease defined as ‘the failure of the adaptive mechanisms of an organism to counteract adequately the stimuli or stresses to which it is subject, resulting in a disturbance in function or structure of any part, organ or system of the body’ (Hoerr and Osol, 1956) remains as a definition of choice for the proposed ontology for the theory of evolution by natural selection.

A concluding comment concerns scenarios where adaptations may be patently or latently deleterious to individual organisms, populations of organisms or ecosystems. Such scenarios can

involve maladaptations or ‘conditions in which biological traits or behavior patterns are detrimental, counterproductive, or otherwise interfere with optimal functioning in various domains, such as successful interaction with the environment and effectual coping with the challenges and stresses of daily life (American Psychological Association, https://dictionary.apa.org/).

Brady et al (2019) discuss the concept of maladaptation from perspectives of ecology and evolutionary biology and the means for reconciling these two perspective in the face of accelerating human-mediated environmental change. Evolutionary biologists have looked to the power of natural selection to produce relative fitness advantages rather than so-called absolute fitness. In contrast, the emphasis by ecologists on changes in abundance and ranges that reflect absolute fitness has overshadowed relative fitness. These two perspectives are bypassed in the proposed ontology for the theory of evolution by natural selection which will concentrate on scenarios where adaptations may be patently or latently deleterious to individual organisms, populations of organisms or ecosystems. Adaptations involved in niche construction, and niche construction by humans are pertinent given the reality of climate change and its implications for One Health.

3.4.6 Species

Darwin gives no particular definition of species in *Origin of Species* (1859, 1872) and presumably followed the usage of his time and place, which is documented in the New English Dictionary (Murray et al.,1888); see Appendix Table A2. Here, a species in zoology and botany is described as: ‘a group or class of animals or plants (usually constituting a subdivision of a genus having certain common and permanent characteristics which clearly distinguish it from other groups’.

In *Darwinism*, Wallace (1889) fixes on definitions of 'species' from the botanist Augustin de Candolle (1778-1841) and the zoologist William Swainson (1789-1855) as follows:

> ‘The term “species” was thus defined by the celebrated botanist de Candolle: “A species is a collection of all the individuals which resemble each other more than they resemble anything else, which can by mutual fecundation produce fertile individuals, and which reproduce themselves by generation, in such a manner that we may from analogy suppose them all to have sprung from one single individual.” And the zoologist Swainson (1835) gives a somewhat similar definition: “A species, in the usual acceptation of the term, is an animal which, in a state of nature, is distinguished by certain peculiarities of form, size, colour, or other circumstances, from another animal. It propagates, ‘after its kind,’ individuals perfectly resembling the parent; its peculiarities, therefore, are permanent".’

Darwin’s *Origin of Species* and Wallace’s *Darwinism* had the effect of challenging long held and seemingly incontestable views about the nature of species. This matter is dealt with in the New English Dictionary (Murray et al.,1888) where the entry on ‘species’ contains the following statement: ‘the exact definition and criteria by which species are to be distinguished (esp. in relation

to genera or varieties), have been the subject of much discussion'. This so-called 'much discussion' about the nature of species persists to the present day and is demonstrated in books on the 'species problem' such as those by Hey (2001), Pavlinov (2013), Richards (2010), Stamos (2003), Wheeler and Meier (2000), Wilkins (2018) and Zachos (2016).

The 'species problem' and 'much discussion' may link to the social attitudes that celebrate privilege and entitlement and which spawned Social Darwinism. In this connection, Darwin (1874) used Chapter VII of *The Descent of Man* to set out 'arguments in favour of, and opposed to, ranking the so-called races of man as distinct species' and relied on flawed evidence to assert that some races had low intellects. Wallace, on the other hand, rejected any species divide within *Homo sapiens* and maintained that 'an Aru islander living in a mud hut has the same mental attributes as a member of London's scholarly Athenaeum club' (Berry, 2013).

However, there are lingering issues around the term species and these have implications for the advancement of biological knowledge and its application. Zachos (2016) provides a list of 32 annotated species concepts. Many concepts in the list are similar. Some may be synonyms and all can be reckoned as suiting a particular purpose within the broad scope of biology.

> 'Here, they can be viewed as operational instruments that allow for particular applications and do not contradict the value of a unifying definition. Mayr (1996) provides a way forward with these words about the biological species concept and how it can cater for other definitions.
> The basic message which emerges from this account of the numerous difficulties of the species problem is that the definition of the biological species must be based on its biological significance, which is the maintenance of the integrity of well balanced, harmonious gene pools. The actual demarcation of species taxa uses morphological, geographical, ecological, behavioral, and molecular information to infer the rank of isolated populations' (Zachos, 2016).

A functional, apt or fit-for-purpose definition of the term 'species' is required for the proposed conceptual framework for the theory of evolution by natural selection and possibilities the are offered by the sample of definitions shown in Table 9. The descriptor, fit-for-purpose or apt, focusses squarely on utility within the practice of One Health and the proposed ontology for the theory of evolution by natural selection. The focus on utility emphasises biology and especially physiology, which is summed up as the science of life (https://www.physoc.org/explore-physiology/what-is-physiology/) and which is the central discipline for delivery of One Health-Planetary Health.

The sources used for Table 9 are the same as those used for the definition of 'evolution' shown in Table 1. Definitions of the term 'clade', which refers to lineages and the branching of lineages, are shown to forestall possible confusion and to emphasise that the term 'clade' is not a synonym for 'species'. The apt or fit-for-purpose definition of 'species' to be distilled from Table 9 must cover sub-cellular and non-organismal entities such as viruses, viroids and prions[60]. These entities clearly

[60]The writings that made for the modern synthesis (Fisher, 1930; Haldane, 1932; Huxley, 1942) contain a single passing reference to a virus being a possible cause of variation in *Drosophila* spp. of fruit-fly (Huxley, 1942).

exhibit Darwin’s ‘descent with modification’ (see section 4.2.8) and must be accounted for in the proposed ontology for the theory of evolution by natural selection.

Table 9: Selected definitions for the terms 'species' and ‘clade’.

	Source	Definition
1,	Abercrombie M, Hickman CJ and Johnson ML (1957) *A Dictionary of Biology.* Penguin Books, Harmondsworth.	Species: The smallest unit of classification commonly used, i.e. the group whose members have the greatest mutual resemblance. For the great majority of animals and many plants, a species is roughly a group of individuals able to breed among themselves (if one disregards geographical separation) but not to breed with organisms of other groups. Clade: Phylogenetic lineage of related taxa originating from a common ancestral taxon.
2.	Grove AJ, Newell GE, Carthy JD (1961) *Animal Biology.* Allen and Unwin, University Tutorial Press, London.	Species: A species may be looked upon as a group of individual animals which in the sum total of their characters (morphological, physiological, etc.) constantly resemble each other to a degree than members of other groups; which form a true interbreeding assemblage, but will not, under natural conditions, produce viable offspring with members of another group. Clade: Absent.
3.	Raven PH, Evert RF and Eichhorn SE (1992) *Biology of Plants, Fifth Edition*. Worth Publishers, New York.	Species: Groups of populations that resemble one another relatively. Cladistics: System of arranging organisms following an analysis of their primitive and advanced features so that their phylogenetic relationships will be reflected accurately.
4.	Stevens PF (1992) Evolution. Species, historical aspects. In: *Keywords in Evolutionary Biology* (Edited by Keller EF and Lloyd EA). Harvard University Press, Harvard, Massachusetts. *Keywords in Evolutionary Biology* has two other Chapters on species: Species, theoretical contexts (Dupré J) and Species, current concepts (Williams MB)	Species: The development of the species concepts is a complex story. Some taxonomists have insisted that the act of describing species affords no room for conceptualization; taxonomists simply describe nature, a matter not of theory but of direct observation. Others, perhaps the majority, have utilized some reproductive criterion in their species concept—either the species is not fertile when crossed with other species, or at least the characters used to distinguish the species are constant over successive generations. There has been general agreement that species must be readily recognizable. In practice, however, the absence of absolute criteria for distinguishing species has prompted recourse to authority and tradition, and these have been used to justify stasis. Clade: Not given.
5.	Freeman S and Herron SC (2001) *Evolutionary Analysis, Second Edition.* Prentice Hall, Upper Saddle River, New Jersey.	Species: Groups of interbreeding populations that are evolutionarily independent of other populations. Clade: Set of species descended from a single common ancestor, synonymous with monophyletic group.
6.	Hickman CP, Roberts LS and Larson L (2001)	Species: A group of interbreeding individuals of common

	Source	Definition
	Integrated Principles of Zoology, Eleventh Edition. McGraw Hill, New York.	ancestry that are reproductively isolated from all other such groups; a taxonomic group below a genus and designated by a binomen consisting of the genus and species name. Clade: A taxon or other group consisting of an ancestral species and all of its descendants forming a distinct branch on a phylogenetic tree.
7.	Mayr E (2001) *What Evolution Is*. Basic Books, New York.	Biological species: Groups of actually or potentially interbreeding natural populations that are reproductively isolated from other such groups. Clade: Portion of a phylogenetic tree between two branching points or from a branching point to the end of the branch.
8.	Campbell NA and Reece JB (2002) *Biology, Sixth Edition.* Benjamin Cummings, San Francisco.	Species: A group whose members possess similar anatomical characteristics and have the ability to interbreed. Clade: Each evolutionary branch of a cladogram (dichotomous phylogenetic tree).
9.	Ridley M (2004) *Evolution, Third Edition*. Blackwell Publishing Company, Oxford.	Species: An important classificatory category, which can be variously defined by the biological species concept, ecological species concept, phenetic species concept, and recognition species concept. The biological species concept, according to which a species is a set of interbreeding organisms, is the most widely used definition, at least by biologists who study vertebrates. A particular species is referred to by a Linnaean binomial, such as *Homo sapiens* for human beings. Clade: A set of species descended from a common ancestral species. It is a synonym for monophyletic group.
9.	Ridley M (2004) *Evolution, Third Edition*. Blackwell Publishing Company, Oxford.	Species: An important classificatory category, which can be variously defined by the biological species concept, ecological species concept, phenetic species concept, and recognition species concept. The biological species concept, according to which a species is a set of interbreeding organisms, is the most widely used definition, at least by biologists who study vertebrates. A particular species is referred to by a Linnaean binomial, such as *Homo sapiens* for human beings. Clade: A set of species descended from a common ancestral species. It is a synonym for monophyletic group.
10.	Zimmer C and Emlen DJ (2016) *Evolution, Making Sense of Life Second Edition*. WH Freeman and Company, New York,	Biological species concept: The idea that species are groups of actually (or potentially) interbreeding natural populations that are reproductively isolated from other such groups. Clade: Single 'branch' in the tree of life; each clade represents an organism and all of its descendants
11.	Futuyma D and Kirkpatrick M. (2017) Evolution, Fourth Edition. Sinauer Associates,	Species: In the sense of biological species, the members of a group of populations that interbreed or potentially

	Source	Definition
	Sunderland MA.	interbreed with one another under natural conditions. Also, a fundamental taxonomic category to which individual specimens are assigned, which often but not always corresponds to the biological species. See also biological species, phylogenetic species concept. Biological species: A population or group of populations within which genes are actually or potentially exchanged by interbreeding, and which are reproductively isolated from other such groups. Clade: The set of species descended from a particular ancestral species

Entries 5 to 11 in Table 9 can build to a definition of species suited to the proposed contology for the theory of evolution by natural selection. These entries post-date the introduction of the so-called biological species concept (Mayr, 1996) which builds from the broad subject of biology as the study of living things and their vital physical and chemical processes and which emphasises microevolution rather than macroevolution. The result is the physiology-focussed precising definition of a species shown below. This definition can encompass viruses and prions.

> *Species are discrete populations of organisms (some of which are holobionts, see section 4.2.3) or sub-cellular and non-organismal life forms such as viruses, viroids and prions (so-called semibionts, see sections 4.3.5 and 4.3.6) which share structural and functional attributes. Some of these attributes implement and control the propagation and exchanges (vertical, horizontal or both) of genetic material*[61] *as whole genomes through successive generations. These attributes create barriers to reproduction and opportunities for reproduction that demarcate one discrete population from another. Species contain subsets or subpopulations*[62] *with diverse capabilities that provide for variation.*

The phrase ‘implement and control the propagation and exchange of genetic material through successive generations’ seeks to elaborate on ‘reproductive isolation’ as the central feature of a species according to the definitions of Hickman et al. (2001), Mayr (2001) and Zimmer and Emlen (2016) shown in Table 9. Species as populations[63] can be isolated geographically. Most importantly, however, populations can be ‘isolated’, demarcated or circumscribed by physiological mechanisms that restrict transmission of genetic material and which arise from shared structural characteristics and capabilities for function. The attributes that act as mechanisms to create the species boundary

[61] As explained in section 4.2.8, the genetic material of prions is protein not DNA or RNA.

[62] The terms suprapopulation, infrapopulation and component populations have a particular use within the discipline of parasitology (Bush et al., 1997; Margolis et al., 1982) and are not apt for present purposes. A suprapopulation is all individuals of a species of parasite in all stages of development within all hosts in an ecosystem. An infrapopulation is all individuals of a species of parasite occurring in an individual host.

[63] Definition: A population is any complete group with at least one characteristic in common. Populations are not just people. Populations may consist of, but are not limited to, people, animals, businesses, buildings, motor vehicles, farms, objects or events (Australian Bureau of Statistics: https://www.abs.gov.au/statistics/understanding-statistics/statistical-terms-and-concepts/population).

will operate according to properties that emerge at successive levels of biological organisation. The lower levels may involve (1) protein receptors that receive and transduce chemical signals and regulate ingress and egress to and from cells, tissues and organisms, and (2) codes that emerge from nucleotide sequences in informational macromolecules and which allow or disallow associations. The higher levels may involve innate and learned behaviours. In short, species are discrete populations of life forms possessing communal properties for reproduction. As an aside, Darwin (1859 and 1872) used the phrase 'incipient species' to describes varieties within a species as 'steps towards more strongly marked and permanent varieties…...leading to subspecies and then to species'.

Note the phrase 'propagation of genetic material[64] as whole genomes through successive generations' in the definitions of Hickman et al. (2001), Mayr (2001) and Zimmer and Emlen (2016). An emphasis on whole genomes can forestall possible confusion arising from mobile genetic elements which are sequences of genetic material that can change places within a genome, and can be exchanged between genomes (modified from Foxman, 2012). Mobile genetic elements include 'plasmids, prophages, pathogenicity islands, restriction and modification systems, transposons, and insertion sequences, among others, that share the ability to be transmitted vertically with cell division or through horizontal transfer' (Vale et al., 2022).

The CRISPR phenomenon exemplifies coding within particular DNA sequences that regulate associations between genomes. CRISPR is an acronym for clustered regularly interspaced short palindromic repeats within DNA sequences that act within prokaryotes as a form acquired immunity to protect against reinfection with bacteriophages (Barrangou et al., 2007). Gatekeeper mechanisms at higher levels of biological organisation are exemplified by the various courtship practices outlined for vertebrates and invertebrates in books on animal behaviour (for example; Alcock, 1989). A last word comes from Loeb (1916) who hints at gatekeeper mechanisms when discussing the chemical basis of genus and species and the phenomenon of specificity: 'The spermatozoon can, as a rule, only enter an egg of the same or a closely related species, but not that of one more distantly related'.

Section 4.2.3 discusses the role of information in the processes of life and reflects on the statement that life depends as much on the flow of information as on the flow of energy (Tkačik and Bialek, 2016). The relevance here is that the structural, functional and behavioural restrictions and permissions described for 'reproductive isolation' act on flows of information. Flows of information can be depicted as crucial for species boundaries and for associations with viruses, prions and virioids (see section 4.2.8).

[64] As explained in section 4.2.8, the genetic material of prions is protein not DNA or RNA.

Chapter 4. Pathways towards a Renewal of Evolution Theory for One Health

‘Slow and steady wins the race’. Aesop (620-564 BCE)

The third and last segment of this ‘one long argument’ or process to renew the theory of evolution by natural selection for present-day use in One Health explores opportunities from information technology (IT) that can facilitate the management of present-day biological knowledge and its advances. Reliable and effective performance in information technology (IT) requires a clear-cut and unambiguous apprehension of ideas, entities and their relationship. The same requirement applies to the present renewal of the theory of evolution by natural selection and can met by adopting an ontology as used in information technology (IT). The words ‘renew’ and ‘renewal’ are apposite in this context because the key elements of the theory of evolution by natural selection are present in the works of Darwin and Wallace but require explication for present-day use according to present-day biological science and the opportunities for organising knowledge provided by information technology (IT).

Items considered around contemporary biology start with issues in the practice of science and include teleology, the nature of explanations and definitions, and the meaning of the words ‘nature’ and ‘theory’(section 4.1). It is proposed that the theory of evolution by natural selection, cell theory and the germ theory of disease form a cohesive and interdependent whole that can guide practice within One Health. Next comes a general survey of the properties, attributes and so on that identify and characterise life and living systems (section 4.2). Considerations extend to terms such as ‘biont, ‘life form’ and ‘organic being’, an overview of thermodynamics and concepts of agency and information that allow for some refined definitions of life. Then follows some detailed explorations of aspects of life relevant to the proposed ontology for the theory of evolution by natural selection (section 4.3). Matters covered are organisation as basic to life, death and its equivalent in life forms, reproduction and inheritance as fundamental to life forms, homeostasis and associated concepts affecting responsiveness and adaptability, associations within and between life forms and viruses and prions as life forms . Last comes an exploration of diagrams or schemes showing the relationship between things and ideas and their value in complementing written text and enhancing the communication of issues associated with the renewal of the theory of evolution by natural selection for application in the One Health (section 4.4).

Artificial intelligence and machine learning are subsets of software engineering that achieve their ends through ideas of knowledge representation and ontological construction (Russell and Norvig, 2010), Ontology, in this context, means a ‘set of concepts and categories in a subject area or domain that shows their properties and the relations between them’ (www.lexico.com) or ‘a structure of concepts or entities within a domain, organized by relationships; a system model’

(https://en.wiktionary.org/wiki/ontology)[65]. The precising definition for present purposes states that ontologies are employed in information technology (IT) to implement machine-readable and interoperable knowledge protocols and give detailed and reliable explanations of the entities, concepts and their relationships in a given area of interest. In essence, the term ‘ontology’ refines the pre-existing notion of a conceptual framework, which can be stated as a hierarchical arrangement of interrelated concepts that allows an explanation and understanding of a subject. Conceptual frameworks and ontologies align easily with Theory A (Science) as a ‘coherent statement or set of ideas that explains observed facts or phenomena and correctly predicts new facts or phenomena not previously observed’ (https://en.wiktionary.org). Conceptual frameworks and ontologies support the quality of scientific models by clearly explaining the variables employed in them and can apply to all modes of rational discourse.

So, the task for this one long argument is to renew the theory of evolution by natural selection as an ontology according to present-day science and with reference to factors in the operating environment for One Health-Planetary Health (Chapter 2) and influences from the history of the theory of evolution by natural selection since Darwin (Chapter 3). The process of renewal will be facilitated by a set of conceptual diagrams which can provide feed-forward and feedback cues for the written text. The written text and conceptual diagram seek to incorporate and expand upon what was called the modern synthesis, accommodate what is sought for in the so-called extended synthesis or third way of evolution, and furnish what is needed from present-day biological knowledge to optimise the utility of the theory of evolution by natural selection across One Health-Planetary Health. The resulting ontology can provide bearings for the vast and sometimes oppressive terminology used in evolutionary biology and genetics and can put an end to diversions such as the arbitrary and esoteric distinction between microevolution (evolution over a shorter term and applying at and below the level of species) and macroevolution (evolution over a longer term and applying above the level of species).

4.1 The theory of evolution by natural selection within the setting of present-day biology

Darwin’s rendition of the theory of evolution by natural selection was limited by the vocabulary and knowledge of biology available to him. The same applies to the work of Wallace and others. The present reformulation at the theory of evolution will build from contemporary scientific knowledge, and contemporary perspectives on science. Most importantly, the reformulation is designed to be open to reasoned revision and the processes of ‘organised scepticism’ (Merton, 1952) as newer knowledge and newer viewpoints emerge. ‘Organised scepticism’ has already driven refinements to the theory of evolution by natural selection and the same ideal underpins One Health.

[65] The word ontology also refers to ‘the branch of metaphysics that addresses the nature or essential characteristics of being and of things that exist; the study of being *qua* being’ (https://en.wiktionary.org/wiki/ontology).

4.1.1 Nothing in evolution [~~biology~~] makes sense except in the light of biology [~~evolution~~]

Dobzhansky (1973) contended that ‘nothing in biology makes sense except in the light of evolution’. Much has changed in the last 50 years and this contention can be re-stated as the corollary: ‘nothing in evolution biology makes sense except in the light cell theory and germ theory’. The two versions combine as a potent whole to guide the following renewal or overhaul of the theory of evolution by natural selection (evolution theory). It is clear that many aspects of biology, such as the circulation of blood in animals (Harvey, 1682) can be fully understood without natural selection theory. For this reason, evolution theory, cell theory and the germ theory of disease[66] are proposed as a cohesive and interdependent whole. This union of theories is mooted for good practice within One Health and is supported as follows[67]. (1) Explanations in both physiology and pathology begin with and centre upon cell theory and the interactions within and between cells, tissues, organs and whole organisms (West, 1984; Slauson and Cooper, 2002). (2) Germ theory comes into play when infection is involved. (3) evolution theory can then follow to add new perspectives and insights to the primary explanations provided by cell theory and germ theory. Cell theory, evolution theory and the germ theory of disease present as the only theories in biology that fit within the denotation of Theory A (Science).

A further perspective comes from Gluckman et al. (2011) who state that evolutionary biology provides an integrated understanding of human biology and medicine. Gluckman et al. (2011) explain that the practice of medicine has tended to focus on the mechanistic or proximate aspects of disease (where guidance comes from cell theory and germ theory) and has neglected the evolutionary or ultimate reasons for disease (where guidance comes from the theory of evolution by natural selection). The following statement from Gluckman et al (2011) can apply across One Health including comparative medicine, agriculture and environmental management: ‘The key principles of evolutionary medicine are that selection acts on fitness, not health or longevity; that our evolutionary history does not cause disease, but rather impacts on our risk of disease in particular environments; and that we are now living in novel environments compared to those in which we evolved’.

A way of unifying and coordinating germ theory, cell theory and evolution theory is prompted by Campbell and Reece (2002) who sought to envisage the enormous scope of biology according to two dimensions. The "vertical" dimension covers the hierarchy of biological organisation from molecules to the biosphere and invokes cell theory. The "horizontal" dimension encompasses the diversity of species across the range of life and life forms and invokes evolution theory. Biodiversitytheory could be a synonym for evolution theory. Evolutionary connections among all

[66]The premise here is that only three theories in biology qualify as Theory A (Science). These are cell theory, theory of evolution by natural selection and germ theory.

[67]Natural selection theory, cell theory and germ theory appear to be the only theories in biology that qualify for the category of Theory A (Science).

organisms and the two dimensions of biology continue as themes in subsequent editions of the textbook.

A diagonal dimension to this panorama of life is now proposed and is shown in Figure 2. It covers associations within and between populations of life forms and can cater for the germ theory of disease (see section section 4.3.6b) and align cell theory, evolution theory and germ theory for application in One Health. Sub-organismal biological entities, viruses and prions are positioned before prokaryotes and eukaryotes in the “horizontal” or biological diversity dimension. The gradient of biological associations in Figure 2 is based on the classification put forward by Odum (1983) and Read (1970). This is recapitulated and embellished in Table 10 to show the line of thought behind categorisation and naming. The germ theory of disease links to the biological associations of amensalisn, where one party is inhibited or destroyed and the other party is unaffected, and parasitism where one party benefits and the other party (the host) is harmed. Amensalism and parasitism are subtypes of symbiosis which has the precising definition of the close and usually obligatory association of two or more life forms of different species living together, not necessarily to their mutual benefit. Figure 2 echoes the epidemiological triangle or triad (Bhopal, 2002; Snieszko, 1974; Thrusfield, 1986), which illuminates disease causation by showing relationships among the host, the environment and the disease agent or condition. Figure 2 provides a setting for the sequence of diagrams that progress to the ontology for evolution theory (section 4.4).

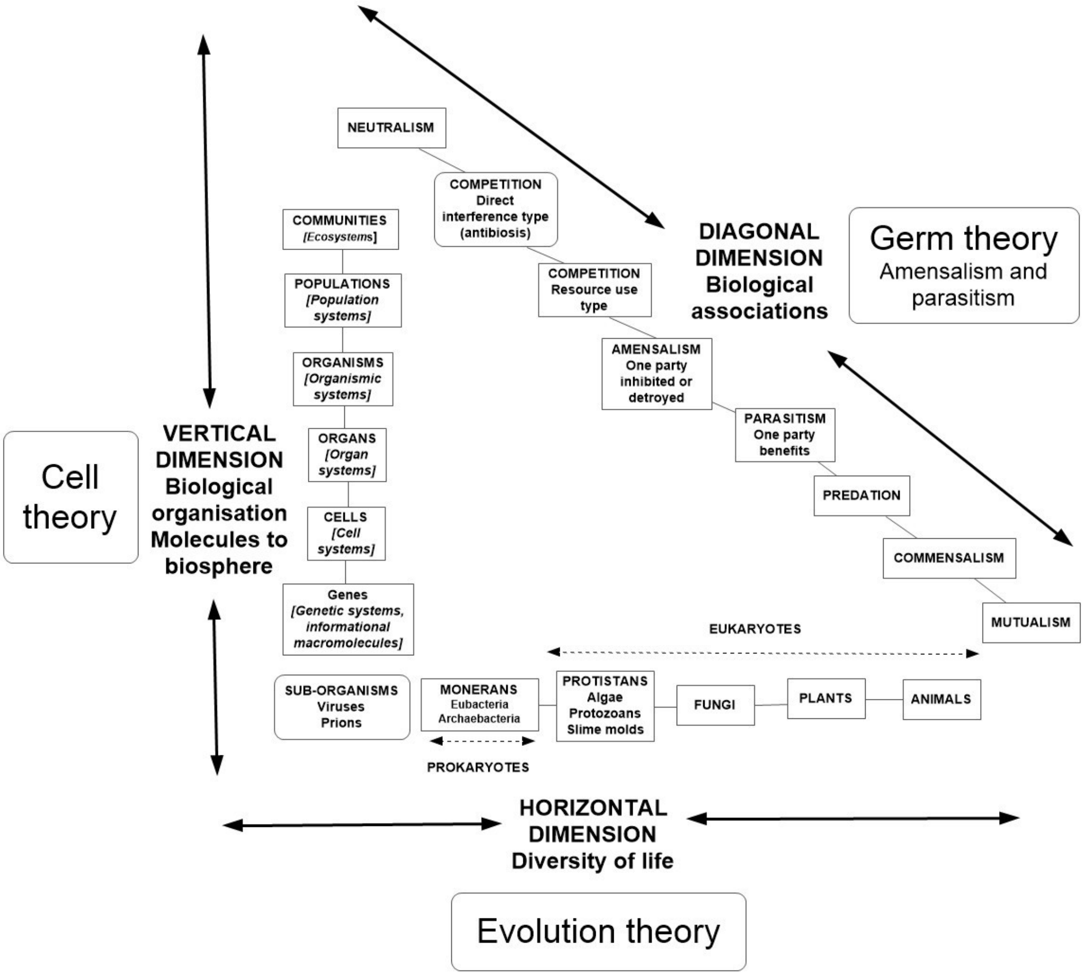

Figure 2: Diagram illustrating life sciences in three dimensions where the vertical branch deals with biological organisation and links to cell theory, the horizontal dimension deals with biological diversity and links to evolution theory, and the diagonal dimension deals with biological associations and links to germ theory. The diagram demonstrates how cell theory, evolution theory and germ theory can operate as a unit for application in One Health.

Table 10: The basis for naming and categorising interactions between populations of organisms.

Interaction category	Party A	Party B	Nature of interaction
1. Neutralism	**0**	**0**	Both parties unaffected
2. Competition – direct interference type	-	-	Direct inhibition of each species by the other
3. Competition – resource use type	-	-	Indirect inhibition when a common source is in short supply
4. Amensalism	-	**0**	One party is inhibited or destroyed and other party is unaffected; for example in infections by viruses and prions, (biological entities and moneran and protistan infectious agents.
5. Parasitism	+	-	One party (the parasite/pathogen) benefits and the other

Interaction category	Party A	Party B	Nature of interaction
			party (the host) is harmed; for example in infections by viruses and prions and moneran and protistan infectious agents and metazoan endoparasites and ectoparasites.
6. Predation	+	-	One party (the predator) benefits and the other party (the prey) is harmed*.
7. Commensalism	+	**0**	One party benefits and the other party is unaffected.
8. Mutualism	+	+	Benefit to both parties – can be either facultative or obligate

*Herbivory is sometimes classified as predation. However, benefits to plants and ecosystems are possible under some conditions of herbivory.

4.1.2 Definitions, explanations and reasoning in contemporary science and the issue of teleology

a. Definitions

This entire effort to renew the theory of evolution by natural selection and the definitions proposed for terms such as evolution, inheritance, selection, adaptation and species depends on the premise that the word ‘definition’ can have a clear and unequivocal meaning that facilitates universal intelligibility within the proposed ontology for the theory of evolution by natural selection (see Section 2). The following functional account of 'definition' suits present purposes and philosophical reflections have provided reference points (Fogelin and Sinnott-Armstrong, 1991; Gupta, 2009; Hurley, 2003): ‘A definition seeks to ascertain and encapsulate the characteristics and nature of a thing and so identify and explain what a thing is’ (modified from Barnhart and Barnhart, 1979; World Book Dictionary). Precising definitions of key concepts and factors in evolution have been constructed to render substance of the ontology intelligible, universally accessible and open to modification in the light of new knowledge. Precising definitions aim at minimising ambiguity and vagueness in particular contexts (Hurley, 2003). Stipulating definitions assign a meaning to a word for the first time. Lexical or dictionary definitions look to the meaning of a word in everyday use. Precising definitions can forestall confusion arising from slipshod jargon and those employed in the ontology are marshalled in the Glossary. Note that mathematical models are compromised and can be counterproductive and sources of harm when their variables are inadequately or wrongly defined. According to George Box (1919-2003)[68], ‘all models are wrong, but some are useful’.

b. Explanations and reasoning

The US National Academy of Sciences (1998 and 1999) and the US National Research Council (2008) set out definitions for theories in science that hinge upon the word ‘explanation’. In

[68]https://en.wikipedia.org/wiki/All_models_are_wrong

consequence, the present task of renewing the theory of evolution by natural selection may be assisted by a philosophical perspective on this crucial word. In this regard, Woodward (2019) refers to the deductive-nomological (DN) model for explanation, which was set out by Hempel and Oppenheim in 1948. According to the DN model, an explanation in science is composed of an *explanandum*[69] (the phenomenon or thing to be explained) and an *explanans*[70] (a collection of propositions that combine to account for the *explanandum*). So, the phrase 'origin of species' in the title of Darwin's book is the *explanandum* and the phrases 'by means of natural selection, or the preservation of favoured races in the struggle for life' refer to the *explanans*. The DN model was not employed by Fisher (1930).

Woodward (2019) describes other models for scientific explanation; the statistical relevance or SR model, the causal mechanical or CM model, the unificationist account of explanation, and pragmatic theories of explanation. The deductive-nomological (DN) model for explanation, however, seems to be appropriate for use in One Health, mainly because it aligns with the causal reasoning used in clinical practice and because fit-for-purpose versions of causal reasoning will apply to agriculture and resource management. Causal reasoning and its alliance with hypothetico-deductive reasoning and iterative hypothesis testing (Blackburn, 2016; see Glossary) is integral to the usual diagnostic processes employed in medicine (Goldman, 1987; Kassirer et al., 2009) and veterinary medicine (Radostits, Tyler and Mayhew, 2000). According to Kassirer et al (2009) causal reasoning is 'an aspect of the diagnostic process based on the cause-and-effect relations between clinical variables and chains of variables. It is a function of the anatomic, physiologic and biochemical mechanisms that operate in the normal workings of the human body and the pathophysiologic behavior of these mechanisms in disease'. Patel et al. (2012) refer to causal reasoning in the context of medical reasoning which they view as an inferential process for making diagnostic or therapeutic decisions or to understand the pathology of a disease process. This reasoning is based on induction, deduction and abduction, where abduction, a term coined by Charles Sanders Pierce (1839-1914) is inference to the best explanation (Douven, 2011).

Causal reasoning and the deductive-nomological (DN) model of explanation will drive the ontology for natural selection theory. Among other things, it can manage issues arising from 'teleology' that have constricted evolutionary thought both before and after publication of the *Origin of Species*. The coupling of descent with modification to natural selection in *Origin of Species* challenged a particular teleological paradigm that development of life on earth reflected the 'unfolding of a coherent plan aimed at a predetermined goal' and belief that the 'world was designed by a wise and benevolent God' (Bowler, 2009). This paradigm operated during the period from about 1880 to 1920, which has been named as the eclipse of Darwinism (Allen, 2014; Bowler, 1989; Ridley, 2004). Unsuccessful attempts were made during this period to falsify or refute the theory of evolution by natural selection. The following period from the 1920s to the 1950s marks the 'modern synthesis' when natural selection and Mendelian genetics were reconciled (Gregor Mendel, b. 1822, d. 1884). The term 'teleonomy' was coined during the period of the modern synthesis to avoid

[69] Plural is *explananda*.

[70] Plural is *explanantia*.

notions of 'natural theology' and 'vitalism' within evolutionary biology. Proponents of this term included Huxley (1942, cited by Mayr 1961), Simpson (1964), Mayr (1961, 1965 and 1982) and Williams (1966).

c. Teleology

The passage of time allows a fresh perspective on teleology and teleonomy in relation to the theory of evolution by natural selection and its impacts on culture, religion and science. A contemporary appraisal of evolution and teleology in relation to religion comes from Ayala (2007). Ayala sets out a case that the theory of evolution can be compatible with religion and can actually benefit religion because it provides an answer to the problem of theodicy[71]. Ayala (2007) refers to the philosopher David Hume to explain theodicy as follows: 'Is God willing to prevent evil, but not able?. Then he is impotent. Is he able, but not willing? Then he is malevolent. Is he both able and willing? Whence then evil?' Ayala's theologically attuned arguments in favour of the theory of evolution by natural selection rebut the teleological paradigm that operated during the eclipse of Darwinism.

A contemporary appraisal of evolution and teleology in relation to science comes from Noble (2016), Noble and Noble (2017) and Corning (2019). Noble (2016) states that 'teleology as purpose in the context of a particular organism–environment interaction makes perfectly good scientific sense; it is verifiable' and that 'teleonomy as apparent teleology' makes no sense if goal-directed behaviour of a living system is clear-cut. the notion of natural purposiveness as described by Noble and Noble (2017) could free teleology from its twentieth century encumbrances.

Goal-directed behaviour is central to the concept of teleology. Such goals hinge upon so-called natural purposiveness, which presents as an emergent property of multi-level evolved systems and which can be recognised according to physiology, the scientific discipline that deals with the functions of living organisms or their parts (Hoerr and Osol, 1956). In consequence, Noble and Noble (2017) see no need to avoid the word teleology. Teleology can align with empirical or *a posteriori* reasoning (Lacey, 1996) and can build upon experience and observation of the natural world. Teleology or teleonomy becomes problematical when *a priori* reasoning is in play (Corning, 2019) and leads to the absurdity that functions arising from structures, including the well known bodily functions, cannot be reasoned as purposeful.

The teleology-teleonomy wrangle is historically significant but can be regarded as irrelevant to the proposed ontology for the theory of evolution by natural selection that can inform One Health. Aetiology will take precedence over teleology and refers broadly to the study of causes and the assignment of causes, origins, or a reasons for something[72]. Aetiology looks to 'reasons for' and teleology looks to 'purpose of'.

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[71] A dictionary definition of theodicy is argument in defence of God's goodness despite the existence of evil.

[72] The American Heritage Dictionary of the English Language, https://www.ahdictionary.com/word/search.html?q=etiology.

Rovelli (2020) provides a useful view of teleology in musings about the implications of organic evolution. Rovelli uses the related and esoteric concept of intentionality which extend to capabilities such as consciousness or sentience that are emergent properties of nervous systems:

> 'Living things do not possess adaptable structures for mysterious reasons: it is only those that have adaptable structures that are living in the first place………………… There is no such thing as intentionality in nature. It isn't design that directs the combination of things, but it is the combination of things that gave rise to intentionality'.

4.1.3 Contemporary meanings of the words 'natural' and 'nature'

The word 'natural' within the theory of evolution by natural selection can have any of three meanings. A single explicit meaning is required to prevent confusion and misconceptions and to facilitate assembly of the ontology in section 5. 'Natural' could refer to Nature A (Essence), Nature B (Forces), or Nature C (Physical World), or all three at once, which would invite equivocation and destroy comprehensibility. As stated earlier, Nature B (Forces) can be discounted as a truism because the concept that the world is understandable and that the things and events in the universe occur in consistent patterns is a critical presupposition in the practice of science (Gauch, 2003). Darwin's main usage of the words 'nature' and 'natural' is consistent with Nature C (Physical World). Nature C (Physical World) corresponds with 'the wild'. Also, Darwin introduces *Origin of Species* with a reference from William Whewell's 'Bridgewater Treatises' (1833-1836)[73] that clearly separates Nature B (Forces) from Nature C (Physical World)'. This is demonstrated in the annotated quotation below. Note that the word 'environment', unlike the words 'habitat' or 'habitation', was not current during Darwin's life time.

> 'But with regard to the material world [invokes Nature C (Physical World)], we can at least go so far as this—we can perceive that events are brought about not by insulated interpositions of Divine power, exerted in each particular case, but by the establishment of general laws [invokes Nature B (Forces)].'

Darwin used the words 'nature' and 'natural' as a contrast with artificial and referred to artificial selection or the selective breeding of animals and plants by humankind in his one long argument for the origin of species by natural selection. Webster et al (1865) provide the following view of 'nature' and natural that can explain Darwin's distinction between artificial selection and natural selection as shown below in an annotated excerpt from *Origin of Species*. 'Nature' refers to the existing systems of things or the established or regular course of things and 'natural' means having to do with the existing system or regular course of things.

> 'Slow though the process of selection may be, if feeble man can do much by artificial selection [selective breeding of animals and plants by humankind], I can see no limit to the amount of change, to the beauty and complexity of the coadaptations between all organic beings, one with another and with their physical conditions of life, which may have been effected in the long course of time

[73]https://archive.org/details/bridgewatertreat01londuoft

> through nature's power of selection [natural selection], that is by the survival of the fittest [the survival of those that are viable][74].'

'Natural' within the theory of evolution by natural selection can be rationally depicted as Nature A (Essence) and this particular meaning will be used to guide the reformulation of natural selection theory. Natural selection will be presented as the result of a process involving interactions between the nature of organisms and the nature of the environment. These interactions involve the attributes, properties, elements, and characteristics of organisms (to be outlined in section 4.2: Table 10) and the attributes, properties, elements, and characteristics of environments. Nature A (Essence) of the environment acts as a passive filter on the Nature A (Essence) of organisms and results in different rates of survival. Noble (2021) states: 'Charles Darwin (1859) introduced the idea of natural selection (a non-intentional filter) as a metaphorical comparison with artificial (intended) selection. There is no actual selection carried out by natural 'selection'. Nature – in this case the different rates of survival – is simply a passive filter'.

4.2 Attributes, properties, elements, conceptions and characteristics that identify and describe life

Nature A (Essence) refers to the nature of life, which encompasses the attributes, properties, elements, conceptions and characteristics that identify life, living entities and viability and which extends to sub-cellular entities such as viruses and prions. These matters have been explored in material published before 2015 and after 2015 when concepts of information and agency transformed definitions of life and living systems (see section 4.2.3). Works by Campbell and Reece (2002), Hickman et al.(2006), Sagan et al. (2010) and Ryan et al. (2014) were chosen for the period before 2015 because of their conceivable influence on education in biology. Table 11 sets out a collection of edited extracts and explanatory notes from these chosen sources. The extracts are deemed relevant to the task of reconstructing the theory of evolution by natural selection around Nature A (Essence). Table 11 provides background for an understanding of how sub-cellular entities (viruses and prions) fit within the scope of life. Table 11 also orients an understanding of the quality gradient in cellular life from flourishing, to ill-health, to disease and then death. The content of Table 11 emphasises biological organisation and cell theory, which is the first dimension of the life sciences as described by Campbell and Reece (2002): see Figure 2.

The following two passages about life date to the 1960s and have been selected to set the scene for Table 11[75] and concepts of life up to 2015. They lay out fundamental notions that can be refined, embellished and extended according to perspectives imported from computer science and software engineering and qualified according to concerns about teleology.

[74]See section 3.3.2 for a commentary on the phrase 'survival of the fittest', which is seen as disruptive and not fit for purpose.

[75]A passage about life from the 1990s: 'Life] This, the distinguishing feature of organisms is best thought of as involving some sort of complex organisation, giving an ability to use energy for self-maintenance and reproduction' (Ruse, 1995).

> ‘Protoplasm as the physical basis of life is a dynamic system of organised matter constantly absorbing and expending energy. Its uniqueness is due to the fact that it uses part of the absorbed energy for its own regeneration and growth; the remainder being largely expended as work and heat’ (Chambers and Stern, 1963).

> ‘Living organisms are then, essentially dynamic and self-maintaining systems perpetually engaged in varied activities and these are always of a 'directive' nature in the sense that they appear to be directed to attain a particular goal or end result, which is of advantage to the organism. Seen as a whole, these vital activities have a cyclic nature since all organisms undergo development, reproduction, and, as individuals, death. This life-cycle, relatively simple in some, exceedingly complex in others, is perhaps the most characteristic feature of living organisms’ (Grove et al., 1961).

Chambers and Stern (1963) describe protoplasm as a highly organised system endowed with properties, the sum total of which is life[76]. The properties referred to are motility, irritability, reproduction and growth. Irritability is an umbrella term for responsiveness and adaptability and is described as the response by organisms to stimuli (Clugston, 2014). The last passage from Grove et al (1961) moves easily to a preliminary definition of an organism as the unit of life or an entity that is capable *per se* of performing and exhibiting the essential properties and characteristics of life. These are organisation and self regulation, metabolism, responsiveness, movement, growth, development, reproduction, life-cycling and evolutionary adaptation. The *World Book Encyclopedia* (2014), which caters for the general reader in the anglophone world, echoes this list by stating that: ‘Nearly all living things share certain basic characteristics. These characteristics include (1) reproduction; (2) growth; (3) metabolism; (4) movement; (5) responsiveness; and (6) adaptation’. Similar listings of the essential characteristics of life can be found in contemplations from the academic discipline of philosophy (Weber, 2018; Mariscal, 2021).

Items in the seventh, eighth and ninth editions of *Encyclopaedia Britannica* dated 1842, 1853-1860 and 1875-1889 (National Library of Scotland, https://digital.nls.uk/encyclopaedia-britannica/archive) show that depictions of life at the time of Darwin and Wallace could be largely intuitive and pitched towards ethereal matters like vitalism. This contrasts with the definition of life that appears in Webster’s dictionary of 1828 and subsequent editions and which corresponds chronologically with the beginnings of physiology and cell theory. Webster’s dictionary sees life as ‘that state of animals or plants, or an organised being, in which its natural functions are performed, or in which its organs are capable of performing their functions’. A transition occurs in the *Encyclopedia Britannica* with an entry on physiology in the ninth edition of (1875-1889), which says: ‘The most obvious and striking character of a living being is that it appears to be an agent, performing action and producing effect on the world outside itself’. Lewes (1891) states that ‘life is a series of definite and successive changes, both of structure and composition, which take place within an individual without destroying its identity’. These insights

[76] ‘Protoplasm is the actual living substance of the cells of animals and plants. It is a highly organised system with properties, the sum total of which is life’ (Chambers and Stern, 1963).

into the attributes and properties that characterise life are not plainly featured in the seminal works of Darwin and Wallace but are essential to the One Health and its guidance by the theory of evolution by natural selection.

The considerations set out in Table 11 date from 2002 to 2014 and lead to a preliminary definition of organisms as units of life. 'An organism is the unit of life or an entity that is capable *per se* of performing and exhibiting the essential properties and characteristics of life, which are organisation and self regulation, metabolism (transformations of matter and energy), responsiveness, movement, growth, development, reproduction, life-cycling and evolutionary adaptation'. Concepts of information and agency, which gained currency around 2015, are expounded in Section 4.2.3 and can provide a present-day definition of life that caters for sub-organismal life forms like viruses and prions.

Table 11: Attributes, properties, elements, conceptions and characteristics that identify and describe life.

Campbell and Reece, 2002	**Hickman et al., 2006**	**Sagan, Margulis and Sagan, 2010**	**Ryan, McGill and Wilson, 2014**
UNIFYING THEMES IN BIOLOGY **1. Emergent properties** Living world has hierarchical organization extending from molecules to biosphere. Novel properties emerge at each step upward through interactions between components at lower levels. **2. The cell** Basic unit of structure and function. Prokaryotic cells in bacteria and archaea, eukaryotic cells in protists, plants, fungi and animals. **3. Heritable information** Continuity of life depends on inheritance of biological information in DNA molecules – encoded in nucleotide sequences. **4. Structure/function** Form and function are correlated at all levels of biological organization **5. Interaction with and responsiveness to the environment** Organisms are open [thermodynamic] systems that exchange materials and energy with their surroundings. An organism's environment	**GENERAL PROPERTIES OF LIVING SYSTEMS** **1. Chemical uniqueness** Living systems assemble large molecules (macromolecules) that are far more complex than the small molecules of non-living matter. **2. Complexity and hierarchical organization** • Living systems demonstrate a unique and hierarchical organization. • Cells are the smallest units of the biological hierarchy that are semiautonomous in their ability to conduct basic function including reproduction. • The appearance of new characteristics at a given level of organisation is called emergence – emergent properties **3. Reproduction** Living systems can reproduce themselves. Life does not arise spontaneously but comes from prior life through reproduction. Interaction of heredity and variation in the reproductive process is basis for organic evolution. **4. Possession of a genetic program** A genetic program provides fidelity of inheritance. In organisms, genetic information	**INTRODUCTION** • Life, … [living] matter that shows certain attributes that include responsiveness, growth, metabolism, energy transformation and reproduction • Life comprises individuals, living beings assignable to groups (taxa). • Each individual is composed of one ore more minimal living units called cells and is capable of [chemical transformations (metabolism), growth and participation in reproductive acts **DEFINITIONS OF LIFE** **Metabolic** Emphasises chemical transformations. **Physiological** Emphasises the functions covered by the discipline of physiology **Biochemical** Emphasises hereditary information in nucleic acid molecules and enzymes that control the rate of chemical. reactions. **Genetic** Emphasises replicating and heritable components of living things **Thermodynamic** Emphasises living things as	**CELLS** • The fundamental unit of life is the **cell**. Some organisms are *unicellular*, having just one cell. [Others] are *multicellular.* • Each cell is a biological factory that carries out the life-supporting functions of taking in nutrients, converting them to chemical energy, and carrying out specialized tasks.. • All cells come into being the same way: they arise from the division of parent cells. • Cells house a remarkable molecule (*deoxyribonucleic* acid or DNA). DNA encodes instructions for living things, directs the production of proteins that conduct the business of life in cells, creates individual organisms, and is sculpted by natural selection to create evolutionary change in species. **THE**

Campbell and Reece, 2002	Hickman et al., 2006	Sagan, Margulis and Sagan, 2010	Ryan, McGill and Wilson, 2014
includes other organisms as well as nonliving factors. **6. Regulation** Feedback mechanisms regulate biological systems. In some cases, regulation maintains homeostasis, a relatively steady state for internal factors such as body temperature. **7. Unity and diversity** Diversity of life grouped into three domains: Bacteria, Archaea and Eukarya. As diverse as life is, we can also find unity. The more closely related two species are, the more characteristics they share. **8. Evolution** Core theme in biology, explains both unity and diversity of life. Natural selection accounts for adaptation of populations to environments through differential reproductive success of varying individuals	(genetic code) is contained in the macromolecule DNA **5. Metabolism** Living organisms maintain themselves by acquiring nutrient from their environment – used to obtain chemical energy and molecular components for building and maintaining the living system. **6. Development** All organisms pass through a characteristic life cycle. **7. Environmental interaction** All animals interact with their environment – respond to to environmental stimuli – have property called irritability. **Life Obeys Physical Laws** Laws governing energy and its transformations (thermodynamics) are particularly important for understanding life.	systems where both material and energy exchanges occur. **Autopoietic** • Autopoiesis refers to self-producing, self-maintaining, self-repairing and self-relational aspects of living systems. Living beings maintain their form by the continuous interchange and flow of chemical components. Cellular autopoietic systems are bounded by a dynamic material made by the system itself – lipid membrane studded with transport proteins fabricated by the incessantly active cell. • Viruses, plasmids and replicating molecules cannot behave as autopoietic systems because they require cells for their continuity and duplication. • Autopoietic entities at even larger levels include ecosystems such as coral reefs, prairies, or ponds.	**CHARACTERISTICS OF LIFE** **1. Life obeys the rules of chemistry and physics** Life is chemistry. In biology, this chemistry is called metabolism. **2. Organisms acquire and use energy** The vast majority of organisms on Earth depend upon energy that originates from the sun. **3. Organisms reproduce** Organisms make more of their own kind. **4. Organisms maintain a stable internal environmenta**l To function, and to counteract fluctuations in their external environment, organisms have to maintain **homeostasis**, a stable internal environment. **5. Organisms are responsive to their external environment** This characteristic is so fundamental that even single-cell organisms display it. Bacteria move in response to chemicals in their habitats…. **6. Organisms evolve** Over time, and as environmental conditions change, species adapt to their surroundings through evolution. Those individuals best equipped to respond to conditions in a habitat are more likely to survive and pass their genes to the next generation.

The four sources used in Table 11 show broad agreement about the attributes, properties, elements, conceptions and characteristics that identify and describe life and these are unified by two commonalities. Firstly, cells are the foundational units of structure and function in living systems. Viruses, plasmids and replicating molecules such as prions cannot exist without cells. Secondly, life and living systems are governed unequivocally and absolutely by the laws and principles of physics and chemistry and that living organisms operate as open thermodynamic systems and driven by information in its broadest sense.

The metabolic, physiological, biochemical, genetic and autopoietic accounts of life presented by Sagan et al (2010) all come down to the action of thermodynamics and regulated exchanges of matter and energy. Nurse (2003 and 2020) used a different approach to come up similar conclusions about Nature A (Essence) as it applies to life. The approach was inspired by the seminal work of Schrődinger that foreshadowed informational macromolecules (‘hereditary molecules’) and life as an open thermodynamic system. Nurse (2020) marshalled notions about cells, genes, evolution by natural selection, chemistry and information to identify three principles that govern life. First is ‘the ability to evolve through natural selection’. Second is that ‘life forms are bounded, physical entities’, which are ‘separated from, but in communication with, their environments’. Principle two derives from the ‘idea of the cell, the simplest thing that clearly embodies all the signature characteristics of life’. It invokes a ‘physicality of life, which excludes computer programs and cultural entities from being considered as life forms, even though they can appear to evolve’. The third principle is that living entities are ‘chemical, physical and informational machines’ that ‘construct their own metabolism and use it to maintain themselves, grow and reproduce’. These living machines are ‘co-ordinated and regulated by managing information’ and thus ‘operate as purposeful wholes’. In saying this, Nurse (2020) echoes the quotation from Grove et al. (1961) that introduces this section.

Principle three of Nurse (2020) is in harmony with concepts of autonomy, agency, ‘autopoiesis’ (as interpreted by Margulis and Sagan (1995) and Sagan et al., 2010) and the ‘chemoton’. The term autopoiesis was coined by Maturana and Varela (1972) and explained further by Luisi (2003) and referred to the self-producing, self-maintaining, self-repairing and self-relational aspects of living systems. The term chemoton, or 'chemical automaton', is described by Ganti (2003) and elaborates on an earlier work published in Hungarian in 1978 [77]. The chemoton, as a model for life and living systems, is ‘composed of three stoichiometrically coupled autocatalytic subsystems: a metabolism, a template replication process [self-replication], and a membrane [bilipid layer] enclosing the other two’ (Van Segbroeck et al, 2009). The chemoton recognises the key role transformations of energy in life. Significantly, works on autopoiesis (Maturana and Varela, 1972; Luisi, 2003) make no mention of energy, thermodynamics, plasma membranes or information. This deficiency has been rectified connecting autopoiesis with notions of energy, thermodynamics and information (Margulis and Sagan,1995; Sagan et al. (2010).

Nurse (2020) elaborates on the role of membranes in life as an open thermodynamic system and describes how compartmentation acts to manage metabolic reactions that need to be separated from one another to allow for function. In short: ‘The cell itself contains successive layers of compartmentation. The largest of these [intracellular] compartments are the membrane-bounded organelles, such as the nucleus and the mitochondria’. Bar-Peled and Kory (2022) enlarge upon compartmentation and explain that it establishes new localised chemical environments, provides protection from reactive metabolites and thus allows the regulation of metabolic pathways. The

[77] Ganti, T. (1978). Chemical systems and supersystems. III. Models of self-reproducing chemical supersystems: The chemotons. *Acta Chimica Academiae Scientarium Hungaricae*, 98, 265–283.

organelles involved in compartmentation can be depicted as command-and-control centres that give rise to metabolic homeostasis.

Four items round off this treatment of Nature A (Essence) as it applies to life and living systems. First is reference to the word ‘biont’. Second is an overview of thermodynamics and its four laws that can inform the proposed ontology for the theory of evolution by natural selection. Reasoned responses to climate change within One Health require a grasp of the essentials of thermodynamics. Third is a consideration of some additional and more recent accounts of the essentials of life and living systems. Foremost are concepts of information, agency and chemical compartmentalisation.

4.2.1 The terms ‘biont’, ‘life form’ and ’organic being’.

‘Biont’ has recently come to the fore as a synonym for an organic being, a life form or organism and may assist in understanding cells and the subsequent hierarchy of living systems where fresh properties arise at each successive level of biological organisation. A ‘biont’ is defined as a discrete unit of living matter (https://www.merriam-webster.com/dictionary) and this definition can embrace viruses and prions (see section 4.3.5). ‘Biont’ has operated as prefix in terms of longstanding such as symbiont (an organism living in symbiosis with another), haplobiont (organism with only one type of individual in its life cycle), diplobiont (organism characterised by at least two kinds of individual in its life cycle, such as sexual and asexual), halobiont (an organism that lives in a salty environment), mycobiont (the fungal component of a lichen) and phycobiont (the algal component of a lichen). It also operates in the term ‘holobiont’ which refers to a host plus other organisms that function as a mutually dependent whole (see section 4.3.5 where ruminant livestock provide a classic example).

The word ‘germ’, which gives meaning to the germ theory of infectious disease, accords with the word ‘biont’ and signifies that the agents of infection possess properties that characterise life.

4.2.2 An overview of thermodynamics

Box 10 provides an overview of the laws and key concepts in thermodynamics that clarify life as an open thermodynamic system that can exchange both matter and energy with its surroundings and with the ability to oppose any descent into disorder and to maintain a stable self-producing, self-maintaining and self-repairing environment within it boundaries. ‘Descent into disorder’ is another way of saying ‘increase in entropy’. The concept of entropy, enthalpy and Gibbs free energy are elaborated in Box 10. Importantly, all four laws of thermodynamics in Box 10 apply to living systems. The second law explains open and closed thermodynamic systems. All four laws illuminate the impact of the physical environment on life and living systems and lie at the heart of responses to the urgent matter of climate change and global warming.

Thermodynamics and its four laws have been made comprehensible to non-specialists (Atkins, 2010; Pauken, 2011; Potter, 2009) and textbooks on biology and animal physiology give good coverage (Campbell and Reece, 2002; Sherwood et al., 2005). Knowledge progresses and it is remarkable that Grove et al. (1961) and Chambers and Stern (1963) discuss the role of energy in living organisms and protoplasm without mentioning thermodynamics and any of its laws. In this regard, the content of a physics textbook and a science dictionary from the 1950s (Booth and Nicol, 1958; Uvarov, 1958) provide a benchmark to show that recent improvements in the presentation of knowledge around thermodynamics have transformed an understanding of biology.

The contents of Box 10 and that in Table 11 show how a contemporary and thermodynamics-based understanding of life converges on the discipline of physiology, which is summed up as the science of life (https://www.physoc.org/explore-physiology/what-is-physiology/). Accordingly, physiology (underpinned by thermodynamics) can be deemed as crucial for proper delivery of One Health in all its parts as expanded by the following four points. (1) Physiology as normal function partners with pathophysiology as compromised function to illuminate the spectrum of health and wellbeing from vigour to disease. (2) Sound practice in natural resources and land use management requires an understanding of energy flows within ecosystems and the hazards confronting all components. (3) Progression to farming and agricultural practices labelled variously as agroecology, bio-sensitive, sustainable, regenerative or nature-based depends unreservedly upon an explicit understanding of thermodynamics. (4) Physiology, based on thermodynamics, provides criteria for assessing the benefits and hazards associated with selective breeding of plants and animals and genetic engineering and the whole of agriculture and natural resources management. Included here are claims about resilience in livestock which make little sense without reference to the limits imposed by thermodynamics.

Box 10: A synopsis of thermodynamics and its significance for life and living systems

I. Thermodynamics

Statement

Thermodynamics studies the laws that govern the conversion of energy from one form to another, the direction in which heat will flow, and the availability of energy to do work. Thermodynamics is based on the concept that in an isolated system anywhere in the universe there is a measurable quantity of energy called the internal energy (*U*) of the system. This is the total kinetic and potential energy of the atoms and molecules of the system of all kinds that can be transferred directly as heat; it therefore excludes chemical and nuclear energy (Daintith. 2009).

A system in thermodynamics refers to a specific region or object of interest, while the surroundings encompass everything else outside of that system. Thermodynamics recognises isolated, closed and open systems. (1) Isolated systems exchange no matter or energy with their surroundings. (2) Closed systems do not exchange matter but may exchange heat and experience and exert forces. (3) Open systems can interact with their surroundings and exchange both matter and energy.

Some implications for life and living systems

Thermodynamics and its four laws elucidate how the flow and transformation of energy within living systems gives rise to the phenomenon of life. Thermodynamics emphasises the need for regulated energy flows to maintain and create an order and organisation that counteracts entropy or disorder. Put simply, energetics and its four laws give indispensable guidance throughout the discipline of physiology, which studies the functions of life and living systems and is described as the science of life.

II. Zeroth Law of Thermodynamics

Statement

If two thermodynamic systems are in thermal equilibrium with each other, and also separately in thermal equilibrium with a third system, then all three systems are in thermal equilibrium with one other. This law is entailed in measurements of temperature.

Some implications for life and living systems

The zeroth law of thermodynamics does not apply directly to the internal workings of living systems. However, it sheds light on energy transfer and equilibrium, and temperature gradients which are crucial to the functioning of life forms and the behaviour of living systems. It also provides an understanding of the various environments that act on life forms and living systems.

III. First law of thermodynamics

Statement

The total energy in a closed system remains constant and can neither be created nor destroyed, although it may be converted from one form to another. Heat and mechanical energy are mutually interchangeable.

Some implications for life and living systems

Three implications for life and living systems from the first law of thermodynamics are:
(1) Energy conservation and balance in metabolism: Living organisms constantly act to obtain energy from their surroundings and use it in their metabolism for performing work, maintaining vital functions, and supporting growth and reproduction.
(2) Energy flow in ecosystems: Ecosystems function as interconnected networks of energy flow. The First Law of Thermodynamics directs this energy transfer from one organism to another and its subsequent cycling through the various trophic levels of the ecosystem. Plant producers convert sunlight into chemical energy, which is then passes to primary consumers (herbivores), to secondary consumers (carnivores), and so on. Some energy is lost as heat at each trophic level,. When regenerative processes are allowed to operate, the total energy within an ecosystem remains constant.
(3) Homeostasis and energy balance: The first law of thermodynamics applies to homeostasis and energy balance in that energy intake must equal energy expenditure if organisms are to maintain a stable internal environment.

IV. Second law of thermodynamics

Statement

(1) The entropy of an isolated system tends to increase over time, where entropy is a measure of the disorder or randomness within a system. (2) Heat always moves from hotter objects to colder objects, unless energy in some form is supplied to reverse the direction of heat flow. (3) Not all heat energy can be converted into work in a so-called cyclic process. (4) The law describes the amount of work that can result from a transfer of heat.

Some implications for life and living systems

The second law of thermodynamics sets limits on the efficiency and organization of energy transformations in living systems. It highlights the challenge faced by organisms to maintain order and complexity while contending with the natural tendency towards increasing entropy. Understanding the Second Law helps in comprehending the energetic constraints and evolutionary processes that shape the dynamics of life and living systems.

V. Third law of thermodynamics

Statement

(1) As the temperature of a system approaches absolute zero (0 Kelvin or -273.15 degrees Celsius), the entropy of the system approaches a minimum value. (2) the entropy of a closed system at thermodynamic equilibrium approaches a constant value when its temperature approaches absolute zero.

Some implications for life and living systems

The implications of the third law of thermodynamics for life and living systems are mainly indirect. It provides insights into the behaviour of matter and energy at extremely low temperatures. It helps in the study of cryobiology, energy barriers in chemical reactions, and the fundamental limitations imposed by temperature on biological processes.

VI. Terms used in thermodynamics

Entropy

(1) A parameter representing the state of disorder of a system at the atomic, ionic or molecular level; the greater the disorder, the higher the entropy (Lafferty and Rowe, 1993). (2) The measure of a system's thermal energy per unit temperature that is unavailable for doing useful work. Because work is obtained from ordered molecular motion, the amount of entropy is also a measure of the molecular disorder, or randomness, of a system (Encyclopedia Britannica Ultimate Reference Suite, 2010).

Enthalpy

(1) In chemistry, alternative term for the energy of reaction, the heat energy associated with a chemical change (Lafferty and Rowe, 1993). (2) The sum of the internal energy and the product of the pressure and volume of a thermodynamic system. Enthalpy is an energy-like property or state function—it has the dimensions of energy, and its value is determined entirely by the temperature, pressure, and composition of the system and not by its history (Encyclopedia Britannica Ultimate Reference Suite, 2010).

Free energy

(1) A measure of a system's ability to do work. The Gibbs free energy (or Gibbs function), G, is defined by $G = H - TS$, where G is the energy liberated or absorbed in a reversible process at constant pressure and constant temperature (T), H is the enthalpy, and S the entropy of the system (Daintith, 2009). (2) Energy-like property or state function of a system in thermodynamic equilibrium. Free energy has the dimensions of energy, and its value is determined by the state of the system and not by its history. Free energy is used to determine how systems change and how much work they can produce (Encyclopedia Britannica Ultimate Reference Suite, 2010).

Equation (Gibbs free energy equation)

The equation that links entropy (S), enthalpy (H), and Gibbs free energy (G) is known as the Gibbs free energy equation. It is expressed as: $\Delta G = \Delta H - T\Delta S$ where: ΔG represents the change in Gibbs free energy, ΔH represents the change in enthalpy, T represents the temperature in Kelvin, and ΔS represents the change in entropy.

4.2.3 The concept of information within the nature of life (Nature A, Essence) and its implications for diversity, genetics and evolvability.

The concept of 'information' (Farnsworth, 2022; Hansen et al., 2021; National Academies of Sciences, Engineering and Medicine, 2022; Tkačik and Bialek, 2016) and the way it can revolutionise perspectives on the attributes of life and living systems is absent from Table 11, which demonstrates that science continues to advance. Tkačik and Bialek (2016) state that 'life depends as much on the flow of information as on the flow of energy'. This idea is reflected in the following quote from a report by the US National Academies of Sciences, Engineering and Medicine (2022): 'But life depends not only on energy; it also depends on information. Organisms and even individual cells need information about what is happening in their environment, and they need information about their own internal states'. Dubois (2007) states that 'to become "living," an assembly of biogenic molecules must contain the information needed for its further development and must be able to transmit this information to its progeny. … even in its simplest manifestations, life is historical; it embodies the past and carries instructions for the future'. Present-day physics allows a 'deeper understanding of the connections among energy, entropy, and information' and the thermodynamic processes that lead to life[78].

Dictionary accounts of the transitive verb 'to inform' automatically extend to the noun 'information' and empower its use in the proposed ontology for the theory of evolution by natural selection. Two meanings of 'to inform' from *Webster's New World Dictionary* (1986) are (1) 'to give form or shape to; to give vital or organizing power to; to give life to; to imbue and actuate with vitality; to animate; to mold; to figure; to fashion' and (2) 'to give knowledge of something; to tell, acquaint with a fact etc'. A more recent account (https://www.merriam-webster.com/dictionary/inform, accessed on January 15, 2023) says much the same: '(1) to communicate knowledge to and (2) to give character or essence to. In short, information refers to an informing or being informed'.

Other dictionary accounts of the words 'to inform' and 'information', however, signal the possibility of linguistic confusion. This can be circumvented by means of a definition suited to the ontology for the theory of evolution by natural selection and its aim of overcoming language barriers. *The Oxford Dictionary of English* (Soanes and Stevenson, 2005) defines inform and information as follows and this does not extend to meaning (1) from *Webster's New World Dictionary* (1986), which is the definition of choice for present purposes.

> Information: 1. facts provided or learned about something or someone (e.g. a charge lodged with a magistrates' court); 2. what is conveyed or represented by a particular arrangement or sequence of things (e.g. genetically transmitted information, computing data as processed, stored, or transmitted by a computer). Inform: 1. give (someone) facts or information, tell, give incriminating information about someone to the police or other authority; 2 *[with object]* give an essential or formative principle or quality to (*religion informs every aspect of their lives)*.

[78] See 'Harnessing the Power of Information – Order and Disorder'. Prof. Jim Al-Khalili, Spark, YouTube (https://www.youtube.com/watch?V=qj7HH0PCqIE).

Clarification and support for the chosen definition from *Webster's New World Dictionary* (1986) comes from the principal historical dictionary of the English language, the *Oxford English Dictionary* (https://en.wikipedia.org/wiki/Oxford_English_Dictionary)[79]. The 1933 corrected reissue of this dictionary has a multitude of meaning for 'inform' and 'information'. One meaning coincides roughly with the chosen definition and is 'to give form to, put into form or shape, to put into material form or shape, frame, mould, fashion – to put into proper form or order, to arrange, to compose'.

The proposed ontology for the theory of evolution by natural selection will act on the premise that information, as defined in *Webster's New World Dictionary* (1986), is the essential bridge or intervening or intermediate variable[80] between structure and function in life forms. The centrepiece of molecular biology refers to the flow of genetic information within a biological system by means of informational macromolecules; DNA and RNA in the case of cellular organisms, DNA or RNA in the case of viruses and protein in the case of prions. In similar vein, information is the intervening variable for stimulus and response phenomena, for the feedback and feed-forward mechanisms that drive homeostasis and allostasis and for the multitude of communication pathways within and between cells.

Food for further thought and future advances comes from Kennedy (2023) who states that 'information processing underlies all life and is a defining characteristic of life' and draws attention to misunderstandings that might arise from the diversity of concepts, terminology, and assumptions about information that operate across science and technology. Kennedy (2023) suggests the terms 'symbolic information' and 'physical information' to distinguish between two fundamentally different concepts of information. Symbolic information applies in biology and is based on 'symbols' created by living entities as part of processes for perception, memory, communication, purposeful action, or planning. Physical information, as used in physics, refers to the concept that any physical non-uniformity, difference, or distinction is information. 'Physical information is a descriptive property of the distribution of matter and energy'.

The notion of information embraces genetics which is the biological discipline concerned with the study of genes, genetic variation, and heredity in life forms. Genetics comes with a set of particular terms that require explanation. The term gene denotes the basic unit of heredity and has a physical manifestation in the chemical structure of the informational macromolecules that make up the genome of a life form, and which can be DNA (deoxyribonucleic acid), RNA (ribonucleic acid) or protein in the case of prions. Genes contain the instructions for making a specific protein or set of

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[79]The full title of this dictionary is: *The Oxford English Dictionary: Being a Corrected Re-issue with an Introduction, Supplement and Bibliography, of A New English Dictionary on Historical Principles: Founded Mainly on the Materials Collected by the Philological Society* (https://en.wikipedia.org/wiki/Oxford_English_Dictionary).

[80]Intermediate variable: A variable that occurs in a causal pathway from a causal (independent) variable to an outcome (dependent) variable (Porta, 2014). Intervening variable; 1. Synonym for intermediate variable (Porta, 2014). 2. A factor mediating the relationship between two other factors (Chandler and Munday, 2011).

proteins. The term allele (or allelomorph) refers to either of the two alternative forms of a gene occupying the same site in genomes of life forms that reproduce sexually. Genomes are the entire set of genes specified in physical form by the associated set of informational macromolecules that predominate in a life form. For eukaryotic organisms, genomes include both nuclear and mitochondrial DNA. Genotype accompanies genome as the genetic composition of a life form.

Variation, selection and inheritance are described as the causes of evolution (Maynard Smith, 1993) and all these factors hinge on the concept of information. The information for variation and inheritance that provides the substance for selection is carried by genes and genomes. Variation implies diversity in the inherited package of genes and this diversity can change and expand over time as a result of mutations which are alterations in the genetic material (the genome) of a cellular organism or virus that can pass from one generation to another. Mutations can occur as large-scale changes such as the loss or rearrangement of a large section of a chromosome or as small-scale changes where there is a substitution, insertion or deletion of one or more nitrogenous base pairs in a section of DNA. In viruses in these small scale changes occur at sections of the DNA or RNA that constitutes their genome. Mutations can can also result from copying errors during the replication of informational macromolecules (DNA or RNA) or through errors caused by exposure to physical or chemical agents classed as mutagens. Evolution progresses in line with mutation rates and the associated changes in heritable information and these rates vary widely among life forms.

Mutation rates in mammalian genomes are at the low end of the range and approximate to 2.2×10^{-9} mutations per base pair per year (Kumar and Subramanian, 2002). Estimates of mutation rates in DNA viruses are at a higher level of the range and are similar to bacteria with about 0.003 mutations per genome per replication (Holmes, 2002). Mutation rates in viruses with RNA genomes are at the highest level of the range and result from the absence of proof-reading mechanisms in their processes for genome replication (Choi, 2012). Dimmock et al. (2016) state that an RNA virus can achieve in one generation the degree of genetic variation which would take an equivalent DNA genome between 300,000 and 3000,000 generations to achieve. This prodigious rate of mutation has major implications for the emergence of infectious viral diseases that challenge One Health.

4.2.4 The concept of agency within the nature of life (Nature A, Essence) and its implications for evolvability.

Another concept, that of ‘agency’, has recent usage, particularly in evolutionary biology and animal behaviour (i.e. ethology). ‘Agency’ pairs with the concept of autonomy shown in Box 11 and the two together have crucial implications for the statement that ‘life depends as much on the flow of information as on the flow of energy’. Agency as used in biology links to the dictionary definition od agency as that which produces a specified effect. The proposed ontology for the theory of evolution by natural selection builds from the Nature A (Essence) of a life form. The biological sense of agency is embedded in this essence and dictionary definition of agency guides the structure of the ontology.

Agency and autonomy have particular meanings within psychology and definitions from psychology contain elements that can elucidate the terms across all biology and illuminate how information and energy integrate as the foundations of life. Agency in psychology (VandenBos, 2015) refers to the state of being active usually in the service of a goal or having the power and capability to produce an effect or exert influence. The key element for the whole of biology is 'the power and capability to produce an effect'. This concurs with the view that an agent 'is a being with the capacity to act', and that 'agency' denotes the exercise or manifestation of this capacity' (Schlosser, 2015). Autonomy in psychology (VandenBos, 2015) refers to a state of independence and self-determination in an individual, group or society. They key element is mention of an individual which can refer to a single separate thing and thus extend the notion of autonomy across life and living systems.

Agency in general biology refers to the capacity of organisms, sub-organismal life forms (viruses and prions) or systems of organisms to act and exert control over actions and to select actions according to information inputs (precising definition). Agency acts to optimise viability in individuals and ecosystems and is exemplified by the phenomenon of niche construction. Agency operates through behaviour which refers to the way in which life forms respond to prevailing conditions or circumstances. Appropriate behaviours, guided by agency, allow for viability and are subjected to natural selection. Autonomy in general biology can be seen the capacity of sub-organisms organisms or systems of organisms to function independently as open thermodynamic systems that entail self-regulation, self-sufficiency, metabolism and homeostasis. In short, agency aligns with information in the general scheme of life and living systems and autonomy aligns with energy.

Agency has been a recent focus in evolutionary biology and the subject of articles (Corning, 2014 and 2020; Newman, 2022), books (Ball, 2023; Corning et al., 2023) and book Chapters (Corning, 2023; Heylighen, 2023; Jablonka and Ginsberg, 2023; Kauffman and Roli, 2023; Newman, 2023; Noble and Noble, 2023; Trewavas, 2023; Uller, 2023; Walsh, 2015) that seek to move evolutionary biology beyond the so-called modern synthesis and incorporate advances in knowledge. Box 11 contains selected passages from Corning (2023) that may assist in explaining agency as it applies in evolutionary biology. They reflect the plain meaning of an agent as a person or thing that performs an action or brings about a result or that is able to do so.

Box 11: Agency and evolutionary biology (extracts from Corning, 2023).

'Agency is a term that is utilized in biology to characterize the ability of a living system to act as an autonomous, self-directed agent—to vary its morphology, its behavior, and its environment "purposefully" in relation to external or internal (physiological) conditions and goals'.

'Agency is thus an evolved capability that enables a living system to respond to variability, and changing conditions, in relation to needed resources and challenges/threats in its environment'.

'Agency in living systems requires: (1) the detection or "perception" of variations in internal and external conditions; (2) the ability to discriminate among these perceptions ("information"); (3) the

ability to purposefully vary behavior, or actions; and (4) “control” or the ability to link information with actions (cf., the cybernetic model of goal-oriented, “feedback”-driven behavior)’.

‘Agency is not dependent upon having a “brain.” It can be based upon simple decision rules. However, its
effectiveness can be greatly enhanced by being able to draw upon prior learning and memory, along with in situ cognitive and problem-solving skills’.

Agency has application within animal behaviour and a role in the delivery of sound animal welfare. Mellor (2020) connects the opportunities of animals to exercise agency with positive affective experiences and states that behavioural choices are the hallmarks of agency which give a sense of being in control and that agency is an animal’s ability to consciously engage in goal-directed behaviours. Reference to internal constitution in the precising definition for agency entails emotional and motivational states (Rolls, 2005) and affective states (Panksepp, 1998). An understanding of how these states are mediated across the kingdom Animalia can guide empathetic and physiology-based animal care.

4.2.5 Refined definitions of life incorporating capabilities for information and agency

The preliminary definition of life for an organism set out in the introduction to this section is now revised according to present day concepts of information and agency as treated in section 4.2.3. This revised version seeks to cover all life forms including cellular organisms and the sub-cellular entities, viruses and prions. It will join the set of definitions that support the proposed ontology for the theory of evolution by natural selection with its basis in information technology. The preliminary definition for cellular organisms (eukaryotes and prokaryotes) is reiterated below.

> An organism is the unit of life or an entity that is capable *per se* of performing and exhibiting the essential properties and characteristics of life, which are organisation and self regulation, metabolism (transformations of matter and energy), responsiveness, movement, growth, development, reproduction, life-cycling and evolutionary adaptation.

The revised definition for eukaryotes and prokaryotes with its refinements is shown below.

> Cellular organisms within the five kingdoms of life are entities with powers for agency and the management, representation and processing of information that allow them *per se* to perform and exhibit the essential properties and characteristics of life, which are organisation and self regulation, metabolism, responsiveness, movement, growth, development, reproduction, life-cycling and evolutionary adaptation.

The revised definition for eukaryotes and prokaryotes is now modified to cater for the nature of life (Nature A essence) in sub-cellular entities, viruses and prions as shown below.

> Sub-cellular life forms, organic beings or bionts exemplified by viruses and prions are entities with powers for agency and the management, representation and processing of information that allow them to take advantage of the cellular machinery of prokaryotes and eukaryotes and realise the essential properties and characteristics of life, which are organisation and self regulation, metabolism, responsiveness, movement, growth, development, reproduction, life-cycling and evolutionary adaptation.

In short, capabilities for agency and the management, representation and processing of information distinguish animate from inanimate entities. An excerpt from Noble and Noble (2023) reinforces the the notion of agency in life and emphasises the value of physiology in illuminating the nature of life for One Health.

> 'Life is purposefully creative in a continuous process of maintaining integrity; it adapts to counteract change. This is an ongoing, iterative process. Its actions are essentially directed to this purpose. Life exists to exist. Physiology is the study of purposeful living function. Function necessarily implies purpose'.

The revised definitions of life for eukaryotes and prokaryotes and for sub-cellular entities, viruses and prions are amalgamated and extended in section 5.2.3 to construct a precising definition of life fitted to the proposed ontology for the theory of evolution by natural selection.

4.3 Aspects of life and living systems requiring further exploration for the proposed ontology for the theory of evolution by natural selection.

Some items in Table 11 (section 4.2) are explored further because of their influence within the ontology or web of concepts applying to the proposed ontology for the theory of evolution by natural selection and because of their links with evolutionary biology. The list of items for further exploration comprises (1) biological organisation, (2) life and death, (3) reproduction and inheritance, (4) homeostasis and kindred ideas applying to responsiveness, adaptability and autopoiesis, which refers to self-regulation, self-maintenance, and self-formation, (5) the notion of viability compared with the notion of fitness, (6) a consideration of the word, population, and how it connects with other words that apply to groups of things, (7) associations within and between species, and (8) a commentary on the nature of viruses and prions.

4.3.1 Organisation as a fundamental concept in biology

The numbered points below seek to provide a synopsis of the concept of biological organisation relevant to an understanding of the theory of evolution by natural selection and how it may apply within One Health. The list has been compiled with help from an account of organisation according to the discipline of physiology (Sherwood et al., 2005).

1. Life is characterised by an order and organisation that allows for patterned transformations of matter, energy and information. Life operates as an open thermodynamic system[81] where chemical and physical mechanisms allow for responsiveness (or its synonym, irritability), growth, metabolism, energy transformation, replication and reproduction, and self-maintenance plus self-regulation, which includes homeostasis and allostasis[82] and so on. The term autopoiesis (Maturana and Varela, 1980) has been given up-to-date sense by Margulis and Sagan (1995) and Sagan et al. (2010) by linking self-maintenance and self-regulation to notions of thermodynamics and information.
2. Cells and their order and organisation are the ultimate vehicle for all life forms which can be either sub-cellular, unicellular or multicellular. Cells provide the machinery manipulated by sub-cellular life forms exemplified by viruses and prions to express the properties of life. In chemistry, elements are the basic unit of matter which cannot be broken down to simpler entities by chemical reactions. In biology, cells are the basic unit of life which cannot be broken down to simpler entities without loss of function.
3. The organisation that allows for life comprises a hierarchy of structural levels where each level builds upon the level below it and creates new capabilities and systems according to the concepts of emergence and emergent properties. Emergence refers to the appearance of new characteristics, or emergent properties, at successive levels of organisation from molecules to whole organisms. Emergent properties are generated by interactions among component parts of a system and emergent properties at one level of organisation are modified by emergent properties at other levels. Consciousness, the waking state in cerebrate animals, is recognised as an emergent property of brain function (Sperry, 1969).
4. The concepts of emergence and emergent properties did not gain currency in textbooks until the 21st century (for example Hickman et al, 2006; Raven et al., 2011). Emergent properties explain structure-function relationships, can eliminate controversies around ‘holism’ and ‘reductionism’ and provide a transformational perspective on fitness in the proposed ontology for the theory of evolution by natural selection. Past perceptions of ‘holism’ and ‘reductionism’ as incompatible opposites (e.g. Koestler and Smythies, 1970) can be reckoned as disruptive either/or fallacies. Reductionistic and holistic approaches occur as interdependent and complementary ways for giving sense within biology (Fang and Casadevall, 2011).
5. Levels of organisation can be seen as systems or ‘regularly interacting and interdependent components forming a unified whole’ and parts of a ‘biological spectrum’ (Odum, 1983).
6. Life depends on both energy and information. Information is the intervening variable or go-between that enables the formation of unified whole by ‘regularly interacting and interdependent components’. Organisms and individual cells need information about their

[81]An open thermodynamic system allows for the transfer of energy and matter between the system and its surroundings. The organisation of living systems allows for this transfer and organisation together with life continues only *while* this transfer continues. The cell membrane is a highly significant structure because it provides the ultimate boundary between the system and its surroundings and *regulates* the exchange of matter and energy (see Box 11).

[82]Homeostasis refers to the maintenance of a steady-state in the internal environment of an organism in the face of fluctuations in the external environment. A*llostasis is complementary to homeostasis and emphasises the dynamic behavioural and physiological mechanisms that are used to anticipate or cope with environmental change to maintain organismal function (Schulte, 2014).*

environment, and their own internal states. Information operates across the biological spectrum from single molecules to groups of organisms.

7. Cells are constructed from atoms formed into four classes of organic molecules (lipids, sugars, amino acids and nucleotides) and then into complex polymeric macromolecules, which are further arranged into a coherent structure of organelles that create a viable whole.
8. Three classes of polymeric macromolecules deliver the structure and function of cells with (1) polysaccharides storing energy, forming protective coats around cells and furnishing structural support; (2) nucleic acids storing, transmitting and helping to interpret heritable information and (3) proteins serving as structural supports and as molecular machines that perform the majority cellular activities of cells (Tobin and Morel, 1997).
9. Cells with their hereditary information (genes) can build to tissues, organs, organisms, populations and biotic communities, which refers to the populations of different organisms occupying a given area and which interact with physical or abiotic factors to form ecosystems (Odum, 1983).

4.3.2 Death in cellular organisms and termination of existence in viruses and prions

A consideration of the attributes, properties, elements, conceptions and characteristics that identify and describe life can be completed by a remark about death. Put simply, death denotes the end or loss of life or the end of existence of an organism and refers to the cessation of processes that sustain life as an open thermodynamic system the termination of the chemical and. physical mechanisms that allow for responsiveness, growth, metabolism, energy transformation, self-maintenance (homeostasis and allostasis), agency and replication/reproduction. Death is an event in the life cycle of a species. This view of death applies easily to animals, plants, fungi, protistans and monerans. Life forms such as viruses or prions possess a limited range of vital or biological functions and the notion of death can refer to the termination of these functions in the same way that a communication device like a telephone can be dead.

Death in cellular organisms is followed by decomposition of each structural level and disintegration of the macromolecules that mediate the functions of life. Viruses and prions, which do not themselves act as open thermodynamic systems, cease to exist or are destroyed when the macromolecules that mediate their functions and allow for viability are disassociated or disintegrated, or both. Death allows for the succession of generations and creates the capacity for Charles Darwin's ‘descent with modification’, otherwise known as evolution.

An understanding of the physiology of death and dying is particularly important within two aspects of One Health. It informs palliative care, which is regarded as a crucial part of integrated, people-centred health services and is thus a component of Sustainable Development Goal 3 (https://www.who.int/health-topics/palliative-care). It also informs the human slaughter and euthanasia of animals as set out in guidelines prepared by the American Veterinary Medical Association (AVMA): AVMA (2016) and AVMA (2020). The matters of palliative care, euthanasia and humane slaughter are important across One Health and society in general (see section 2.3.1).

Death as it applies especially in vertebrates and other animals is a unitary process and the process of dying involves ‘points of no return’ that can be identified (Pallis, 1982a, Pallis, 1982b, Pallis, 1982c, Pallis 1982d and Pallis, 2007). The irreversible cessation of blood circulation is a point of no return since it causes critical centres in the brainstem or elsewhere to die and ends conscious awareness and the integrated function of the whole body. At the ultimate molecular level, death occurs when the absence of chemical energy ends the processes that sustain life. Death refers to the ending of an animal as an integrated whole and not to the death of every single cell in all tissues.

Individual cells making up parts of an organism may die in different ways and without leading to the death of the organism as a whole. Necrosis can be depicted as death of a cell or a portion of tissue differentially affected by local injury (as loss of blood supply, corrosion, burning, or the local lesion of a disease). Apoptosis is crucial for development, tissue homeostasis, and removing damaged or harmful cells and can be depicted as a programmed process of death in cells which systematically dismantle themselves without causing inflammation. Pyroptosis can be depicted as a form of programmed cell death triggered by infection or inflammation and is characterised by cell swelling, membrane rupture, and the release of pro-inflammatory signals. Pyroptosis can have both beneficial and harmful effects on neoplasia

4.3.3 Reproduction and inheritance as fundamental concepts in biology

The points listed after this opening paragraph seek to provide an intelligible synopsis of the concept of reproduction relevant to an understanding of the theory of evolution by natural selection as it applies within One Health. They extend upon an entry on reproduction in Encyclopedia Britannica (Bonner, 2009) and in three ways. First, the necessary and inextricable connection between reproduction and inheritance is enlarged upon. This connection is captured by the following excerpt from the final paragraph of Origin of Species (Darwin, 1872): ‘These laws, taken in the largest sense, being *Growth with Reproduction; Inheritance which is almost implied by reproduction* etc. (see Section 3.3 and Table 6, which contains excerpts from *Origin of Species*). Second, the phenomenon of reproduction is considered more specifically at every level of biological organisation and gives sense to epigenetics and the prenatal transmission of communicable diseases. Third is that reproduction and information are interwoven and reflect the premise that life depends as much on the flow of information as on the flow of energy (Tkačik and Bialek, 2016). Information ‘gives vital or organizing power’ to reproduction and inheritance. Reproduction and inheritance provide the means for intergenerational flows of information and life cycling, which refers to the sequence of changes in a life form as it passes from a given developmental stage to the same developmental stage in the following generation. In short, inheritance refers to the transmission and reception of genetic information from generation to generation via the processes of reproduction.

a. Point by point synopsis of the phenomenon of reproduction and its integration with inheritance and genetics.

Point 1. Reproduction refers to 'making a copy, a likeness, and thereby providing for the continued existence of species' (Bonner 2009) or to 'the process by which a living organism produces other organisms similar to itself' (Rowe and Lafferty, 1993), or 'the process by which a living thing, whether plant or animal, gives rise to another of its kind'[83] (Guyer, 1963). The crux of reproduction is that it occurs throughout the hierarchy of levels in biological organisation starting with replication at the molecular and sub-cellular level of proteins and informational macromolecules (RNA and DNA) and proceeding through each successive level in the spectrum of biological organisation described in section 4.2.1.

> *Origin of Species* (Darwin, 1872) contains the phrase 'inheritance which is almost implied by reproduction' in its last paragraph. This foreshadows that reproduction includes reproduction of the genome, which is the information that guides inheritance.

Point 2. Reproduction and replication are related in meaning. The term replication tends to be restricted to the duplication of informational macromolecules and of cells and subcellular organelles (Lawrence, 2008).

Point 3. Cellular reproduction goes together with cellular differentiation in the overall process of reproduction applying to multicellular organisms. Cellular differentiation refers to the process whereby relatively unspecialised cells change progressively to cells that are more specialised. This results in the tissues, organs and organ systems that make up functionally sufficient multicellular organisms.

Point 4. Certain specialised cells, tissues, organs and organ systems are concerned with the reproduction that allows for the 'continued existence' of species. Cellular reproduction combined with cellular differentiation gives rise to reproductive or germ calls and these provide the medium for inheritance or the acquisition of characteristics by transmission of the complement of genetic information from ancestor to descendant as described in Table 3 (section 3.1). Cells specialised for reproduction are typified by the lineages that give rise to gametes in the case of organisms that reproduce sexually (see point 7).

Point 5. Chemical replication is the base level of reproduction and occurs through duplication (template replication) of informational macromolecules; deoxyribonucleic acid (DNA) in the case of cellular organisms, either DNA or ribonucleic acid (RNA) in viruses and viroids and protein in the case of prions. The term replication unit or replicon refers to a 'DNA sequence that is replicated as a unit from a single initiation site (origin of replication). The genome [either DNA or RNA] of a bacterium or a virus comprises a single replicon; eukaryotes contain a number of replicons on each chromosome' (Hine, 2019). The term replicon extends to sub-cellular entities with a demonstrated capacity for replication. Included here are viruses, plasmids, transposons retrotransposons, viroids,

[83] This particular definition is presented because its phrase 'whether plant or animal' reflects the Linnaean two-kingdom classification of living organisms rather than the contemporary five-kingdom classification and emphasises the need for a present-day perspective on natural selection theory.

virusoids and RNA satellites (see Glossary). Textbooks on genetics (Pierce, 2020; Klug et al, 2020) deal with replicons or replication units and associated concepts such as replisomes and replication factories in their treatment of DNA structures and DNA replication. Duplication by a form of template replication occurs with proteins in prions (see section 4.2.7). Accordingly, prions qualify as units of replication or replicons. As an aside, the capacity of a primordial chemical system to make copies of itself is viewed as a prerequisite for the emergence of life.

Point 6. Cell division is the next level of reproduction. Each of the daughter cells formed during cell division receives about half the mother cell's protoplasmic material but a full complement of DNA. In this way, each daughter cell receives all material and information required for viability and the next round of reproduction.

Point 7. Cell division by binary fission occurs in prokaryotes (monerans, bacteria) with each daughter cell receiving a copy of the single parental chromosome. Cell division by multiple fission can occur in certain algae, protozoans and slime molds. Here, nuclei in cells divide more than once before the cytoplasm separates to form new cells with a single nucleus.

Point 8. Reproduction in uni-cellular and multi-cellular organisms can be either asexual or sexual. Asexual or vegetative reproduction operates when offspring receive their full complement of genetic information from one parent. In sexual reproduction, two parents produce offspring with combinations of genes derived from the gametes of each parent. Gametes are specialized reproductive cells with a haploid number of chromosomes capable of functioning in fertilization or conjugation. Female gametes (ova) are usually non-motile whereas male gametes (spermatozoa) are motile. Female and male gametes and their pronuclei fuse to form zygotes with a diploid number of chromosomes in their nuclei.

Point 9. Reproduction applies to the full life history of organisms and the repeating cycle of adult to fertilised egg. Structures and functions relevant to each stage in the life cycle are reproduced and these lead to reproduced behaviours, where behaviour has the simple meaning of how organisms operate. what they do and what they are capable of doing. Behaviour at this simple level is presented as an umbrella term that embraces concepts of responsiveness to the environment, sensitivity and irritability, which are defining attributes of life (see Table 9). The impossibility of reproduction in mammals without maternal behaviour emphasises behaviour as an obvious concern for evolutionary biology.

- Behaviour specifically defined for animals (Levitis et al., 2009) and plants (Karban, 2008) embellishes the simple meaning of the word and also embraces responsiveness, sensitivity and irritability as attributes of living things.
- For animals, behaviour has been given a precising definition as the internally coordinated responses (actions or inactions) of whole living organisms (individuals or groups) to internal and/or external stimuli, excluding responses more easily understood as developmental changes (Levitis et al., 2009).

- For plants, behaviours are defined as rapid morphological or physiological responses to events, relative to the lifetime of an individual (Karban, 2008).
- Behaviourism as a school of thought in psychology (Graham, 2023) is out of scope for present purposes.

b. More on epigenetics

Epigenetics has had a recent surge of published articles that began in 2001 and peaked in 2021. The term itself has matured and achieved a straightforward present-day meaning that resonates with the illuminating last paragraph in the *Origin of Species* (Darwin, 1872). This paragraphs sums up the processes that produce evolution and its impact on what is now called biodiversity. Darwin (1872) states that the observed phenomena in his representative case (the 'tangled bank') 'have all been produced by laws acting around us' (restated as the factors acting around us). One of these 'laws' or processes, 'variability from the indirect and direct action of the conditions of life, and from 'use and disuse' (better described as usefulness, section 3.4.1), provides a basis for genetics (including epigenetics) that is reflected in the following summation of epigenetics. In short, the way genes are expressed can result from 'the indirect and direct action of the conditions of life'.

Epigenetics is the study of how the behaviour, actions and the environment of organisms can cause changes that affect the way genes work. Epigenetic changes are reversible and do not change DNA sequences. Instead, epigenetic changes affect how DNA sequences (genes) are read and then expressed in phenotypes. Epigenetic changes that affect gene expression include DNA methylation whereby methyl groups added to particular places on DNA chains block the transcription of DNA to RNA, histone modification which can block the transcription of DNA to RNA, and the action of forms of non-coding RNA that switch genes on and off (adapted from US Centers for Disease Control and Prevention, https://www.cdc.gov/genomics/disease/epigenetics.htm).

Two recent definitions of epigenetics and the linked phenomenon of gene expression come from textbooks by Pierce (2020) and Klug et al (2020) and a final word comes from Allis et al. (2015).

1. Pierce, 2020: Epigenetics is the study of the effects of reversible chemical modifications to DNA and/or histones on the pattern of gene expression. Epigenetic modifications do not alter the nucleotide sequence of DNA.
2. Klug et al., 2020: Epigenetics refers to phenomena due to alterations in DNA that do not include changes in the base sequence; often affects the way in which DNA sequences are expressed. Such alterations are often stable and heritable in the sense that they are passed to descendant cells or individuals. Expressivity refers to the degree to which a phenotype for a given trait is expressed.
3. Allis et al., 2015: 'Epigenetics later came to be defined as "nuclear inheritance, which is not based on differences in DNA sequence" (Holliday, 1994)'. Epigenetics can be defined at the macromolecular level as the 'sum of the alterations to the chromatin template that collectively establish and propagate different patters of gene expression (transcription) and silencing from the same genome'.

c. Niche construction and ecosystem engineering

Reproduced behaviours that entail inheritance provide the vehicle for reproduction at levels from organisms through to ecosystems. In doing so, reproduced behaviours are responsible for niche construction which refers to ‘the modification of selective environments by organisms’. Niche construction refers to a causal process where the impact of organisms on their biotic environments leads to changes that have a modifying feedback on the original organisms (Laland et al., 2016; Laland et al., 2017; Odling-Smee, 2024). ‘Evolution thus entails networks of causation and feedback in which previously selected organisms drive environmental changes, and organism-modified environments subsequently select for changes in organisms’ (Odling-Smee et al., 2003; Laland et al., 2011). Niche construction concept has a range of implications for One Health and these merit further exploration and entails processes of reciprocal coevolution. The ‘trade-off’ and ‘arms race’ concepts that address virulence in pathogens (see section 2.4.2) also hinge upon reciprocal coevolution and have ramifications for niche construction.

4.3.4 Homeostasis and kindred ideas applying to responsiveness, adaptability and autopoiesis

As set out earlier and elaborated in Table 11, the essential attributes of life are organisation and self-regulation, metabolism, responsiveness (also known as irritability), movement, growth, development, reproduction, life-cycling and evolutionary adaptation. Self-regulation extends to the self-producing, self-maintaining, self-repairing and self-relational aspects of living systems that make for the up-to-date version of autopoiesis expounded by Margulis and Sagan (1995) and Sagan et al., 2010). The capabilities, processes and mechanisms that mediate these attributes and give expression to viability and fitness form the subject-matter of physiology in all five kingdoms of life. All these matters are illuminated by homeostasis as a descriptor for the idea that ‘the stability of the internal environment is the condition for the free and independent life’ (Bernard, 1865)[84].

Homeostasis is an emergent property of multilevel organised systems and is regarded as the central unifying concept of physiology (Billman, 2020) or the central pillar of modern physiology (Davies, 2016). According to Sherwood et al. (2005), homeostasis joins integration as one of two foundations for modern physiology. Earlier on, Young (1957) states that homeostasis ‘expresses in a word the tendency to self-maintenance that is the characteristic of all living activities’. The notion of homeostasis allows for adaptability or the extent to which an adaptation as defined for the proposed ontology for the theory of evolution by natural selection can operate according to prevailing conditions (see section 3.3.5).

Billman (2020) defines homeostasis as a self-regulating process by which a cellular organism can maintain internal stability while adjusting to changing external conditions. Other aspects of

[84] The physiologist, Claude Bernard (1813-1878), is not referenced in the sample of books from the field of biology that reflect different stages of thought about the theory of evolution; see section 3.2.

homeostasis set out by Billman (2020) are relevant to the proposed ontology for the theory of evolution by natural selection and are paraphrased as follows:

- Homeostasis is a dynamic process that can change internal conditions as required to survive external challenges. Homeostasis is not static and unvarying.
- Homeostatic regulation is more than the product of a single negative feedback cycle and reflects the complex interaction of multiple feedback systems modified by higher control centers.
- Hierarchical control with feedback redundancy results in a finer level of control and a greater flexibility that enables the cellular organism to adapt to changing environmental conditions.
- The health and vitality of the organism can be regarded as the end result of homeostatic regulation. An understanding of normal physiology depends on this concept.
- Disruption of homeostatic mechanisms leads to disease, and interventions must be directed toward re-establishing these homeostatic conditions. To illustrate, antibiotic therapy re-established homeostasis by terminating the disruption caused by bacterial pathogens.

Capabilities, processes and mechanisms that are enlightened by the concept of homeostasis as described here include allostasis, inflammation, immune responsiveness, proteostasis, stress responsiveness, thermoregulation (including acclimatisation and acclimation), genome integrity (including the DNA damage response) and tissue integrity and repair. These entities complement one another to underpin causal reasoning within One Health. Difficulties arise when homeostasis is narrowly defined and refers only to the extracellular fluid of multicellular organisms. The concept of homeostasis applies to unicellular organisms. Pommerville (2011) defines homeostasis for bacteria, protozoa and fungi as the tendency of an organism to maintain a steady state or equilibrium with respect to specific functions and processes.

- Schulte (2014) explains that allostasis refines upon homeostasis and emphasises the dynamic behavioural and physiological mechanisms that are used to anticipate or cope with environmental change to maintain organismal function.
- Meizlish et al. (2021) explain that the broad concept of homeostasis can facilitate an understanding of tissue biology and inflammation. Medzhitov (2021) describes inflammation as an integral part of animal biology that defends against environmental harms and preserves the function of homeostasis and the integrity of tissues and organs.
- Burnet (1962) clearly intimated homeostasis in discussing how immune responses act in maintaining the integrity of the body.
- Proteostasis is a synonym for protein homeostasis (Hoppe and Cohen, 2021).
- Schulte (2014) describes how stress responsiveness nests within homeostasis.
- Morrison and Nakamura (2019) describe how mammalian homeothermy, the maintenance of a relatively constant body core temperature, depends upon the interplay of many autonomously regulated homeostatic variables.
- The broad concept of homeostasis in maintaining the stability of life forms is proposed to operate silently as a guide to understanding genome stability and the DNA damage response, as described in works such as those by Carusillo and Mussolino (2020), Giglia-Mari et al. (2011, Nakad and Schumacher (2016) and Ye et al. (2021).

- Meizlish et al. (2021) give an account of tissue homeostasis as a collection of circuits that regulate the tissue environment, and how the functional organisation of tissues allows for both tissue and overall homeostasis.

a. <u>Phenotypic plasticity and reaction norm</u>

Terms such as phenotypic plasticity and reaction norms that are employed in evolutionary biology are given practical sense by the concept of homeostasis. Phenotypic plasticity refers to the 'pattern of phenotypic expression of a single genotype across a range of environments' (Zimmer and Emlen, 2016). Reaction norms are 'patterns of phenotypic expression of a single genotype across a range of environments'. 'In a sense, reaction norms depict how development maps the genotype into the phenotype as a function of the environment' (Zimmer and Emlen, 2016). Neither phenotypic plasticity nor reaction norms can exceed the limits of homeostasis, which are imposed by the laws of thermodynamics. Phenotypic plasticity and reaction norms emphasise the environmental limits of an organism and define rational boundaries for animal and plant breeding, regardless of advanced methodologies. Similarly, the resilience of animals and plants currently sought for with selective breeding and in regard to climate change cannot exceed the limits of homeostasis. Reaction norms refer to the range of possible phenotypes from a given genotype and phenotypic plasticity refers to the assemblage of latent life sustaining capabilities within a given phenotype and extends to the notion of a cline or the graded series of different forms of the same species in different places.

4.3.5 Associations within and between life forms

Levels of organisation seen as systems or 'regularly interacting and interdependent components forming a unified whole' include the associations that occur between populations of different species (or life form) and those that occur within populations of a single species (or life form). These two classes of association require further elaboration because they come within the sphere of the theory of evolution by natural selection its application within One Health.

As explained earlier (see Figure 2 and Table 10), associations between populations of different species include those named as predation, parasitism, commensalism, mutualism and competition, with symbiosis referring to any intimate association between two or more species of organisms (Odum, 1983; Read, 1970). Infections and infestations can be added to the list and these associations have affinities with predation, parasitism and amensalism. Odum (1983) states that the literal meaning of symbiosis as 'living together' does not necessitate benefit to both parties. The primary meaning of symbiosis in a twentieth century dictionary of biology (Abercrombie et al., 1951) is an 'association of dissimilar organisms whatever the relationship between the two partners' and this meaning echoes within similar twenty-first century dictionaries (Clugston, 2014; Lawrence, 2008). Odum's viewpoint on symbiosis is followed in the present discourse to assist with clarity and to enhance an understanding of viruses.

Predation, parasitism and mutualism (along with infections) are associations that are predicated upon dependencies. Life for predator species depends upon the existence of prey species. Life for parasite species and that for infectious agents depends upon the existence of host species. Life for mutualist species depends upon the existence of partner mutualist species. The rumen flora within artiodactyls like cattle and sheep illustrate mutualism. Cattle and sheep cannot exist without their rumen flora and rumen flora cannot exist without the rumen of cattle and sheep. These dependencies will be affected by the forces of evolution and frame individual ruminants and their rumen flora or microbiota as holobionts. The holobiont concept refers to phenomena that are plainly obvious. The simple concept of a holobiont will be incorporated unreservedly into a renewal of the theory of evolution by natural selection where it can extend the reach and impact of One Health. 'Holo' is derived from the Ancient Greek, hólos, meaning whole; and 'biont' refers to a 'discrete unit of living matter' (see section 4.2).

Hickman et al. (2006) define parasitism as the condition of an organism living in or on another organism (the host) at whose expense the parasite is maintained. Parasitism is further described as a symbiosis that causes harm. The definition of Hickman et al. (2006) is the one of choice for present purposes. Its emphasis on organisms has ramifications for an understanding of how the theory of evolution by natural selection can be applied to viruses, given their nature as infectious agents 'at the edge of life'.

As an aside, Anderson and May (1992) coined the terms 'microparasite' and 'macroparasite' to shape their extensive work on mathematical modelling of infectious disease dynamics. Microparasites are said to be those parasites which have *direct reproduction*, usually at very high rates, within the host (Anderson and May, 1979b) and tend to be characterized by small size and a short generation time. Macroparasites are those having no *direct reproduction* within the definitive host (Anderson and May, 1979b) and includes most parasitic helminths and arthropods. *Direct reproduction* can be taken to mean the proliferation or multiplication of parasite populations within infected hosts. Macroparasites expand their populations by infecting multiple new hosts.

The symbiosis occurring between species has a counterpart within the associations that operate for populations of a single species. Beneficial symbiosis (mutualism) and harmful symbiosis (predation and something similar to parasitism) are both possible within populations of single species. Sexual reproduction, which is an absolute requirement for life in the kingdom Animalia, cannot occur without mutualism. Mutualism reminds that behaviour (what organisms do and how they do it) as well as anatomy (structure) and physiology (function) is shaped through the evolutionary fundamentals of inherited variation and selection. Behaviour in animals refers to observable activities and mutualistic behaviour can be essential for nutrition, reproduction and protection against predators in a wide range of birds and mammals.

Mutualistic behaviours are an essential part of life for animals other than birds and mammals. This is demonstrated by the Allee effect where individuals in a population have lower fitness (reduced survival or reproduction) at low population densities because of difficulties in finding mates and

other cooperators and reduced group defences against predators (Courchamp et al., 2008). A special term, eusociality[85], was coined to describe the mutualism that allows for colonies in insects such as ants, bees and wasps (Ryan et al., 2014). Eusociality, together with matters like kin selection, group selection, altruism and inclusive fitness form the subject matter of sociobiology, which examines social behaviour in the light of evolution. Sociobiology allows a particular perspective on the levels of organisation that form a biological spectrum. The history set out below may help towards an appreciation of how sociobiology fits within the operational landscape of One Health.

Hamilton (1964a and 1964b) inquired into kin selection and used the concept of inclusive fitness to demonstrate mathematically that the theory of evolution by natural selection can extend to cooperative social behaviour and is consistent with the mathematical model known as game theory (Axelrod and Hamilton, 1981). Nowak et al. (2010) suggested that mathematical descriptions of kin selection and inclusive fitness did not necessarily cover the evolution of social behaviour and went on to say that the generalities of the theory of evolution by natural selection provide a better approach to the commonplace field observations of social behaviour and the evaluation of explanatory hypotheses. Abbot et al. (2011) replied with an opposing opinion and this was followed by a round of commentaries directed at details in the two opinions (Bourke, 2011; Birch, 2014; Birch, 2017; Woodford, 2019). Both sides of this dispute used theory in the sense of Theory B (Idea) not Theory B (Science) and all arguments in the dispute actually corroborated the reality of cooperative social behaviour.

The foregoing dispute within sociobiology and about altruism highlights the linguistic, conceptual and procedural problems that can be remedied by a renewal of evolution theory tailored to the needs of One Health. Impediments to intelligibility include the use of figurative language, argumentative rather than expository discourse, and the polysemous nature of words. The popularisation discourse used in science communication (Sterk and van Goch, 2023) can have major downsides if it misinterprets or misinforms (Goldstein et al, 2020). Keller and Lloyd (1992) and Laland and Brown (2002) discuss the impact on evolutionary biology of confusing terms and concepts and terms obscured by multiple concurrent and historically varying meanings.

Four lessons from discourses around sociobiology and 'altruism’ can be applied to the renewal of the theory of evolution by natural selection for application in One Health. First is that the existence of one means to an end (for example, inclusive fitness as a mechanism towards cooperative behaviour) does not and can not foreclose on the possibility of other means towards the same or similar ends. Second relates to the full disclosure model of science (section 4.1.3) and the nature of causation (section 4.1.4). Third is the value of disciplined systematic reviews (see Kahn et al, 2003; Institute of Medicine, 2011) for addressing uncertainties and their nature within One Health and for fostering the constructive discussion implicit in solidarity. The fourth lesson relates to the troubled notion of altruism, which is paraphrased from Queller and Strassman (2014) as a behaviour costly to the performer but a help to others. Queller and Strassman (2014) go on to say that the

[85] Eusociality: A social organization that includes reproductive division of labor, cooperative brood care, and overlap of generations (Keller and Chapuisat, 2014).

'phenomenon of altruism suggests that selection may sometimes operate at levels above that of the individual organism'. Altruism has been a topic within the study of animal behaviour and it is stated that: 'Whenever one is tempted to use the word altruism, it is usually possible to convey what is interesting about the phenomenon without using the word at all' (Dawkins, 1981).

The existence of altruism as part of mutualism has a history of robust discussion within the field of sociobiology. However any lingering doubt about its existence can be easily resolved through the scientific method, which comprises observation reason and experiment or testing (Feynman et al., 2011). Mutualism and altruism based on cooperative behaviour is clearly observable as instanced by parental behaviour, both maternal and paternal, especially in mammals and birds. The important question for the present endeavour is how and where the theory of evolution by natural selection may provide insights into sociality and biological associations that can enhance delivery of One Health.

The word 'competition' has 'past and present meanings….in the discourse of evolutionary biology' (Keller and Lloyd, 1992). Darwin linked the word 'competition' with 'struggle for life and emphasised that 'struggle for life' had a metaphorical not literal sense (McIntosh, 1992). 'Competition' in Darwin's metaphorical and evolutionary sense referred, however, was set aside to suit the ideology of Social Darwinism, as intimated in Bowler (1969), Levine and Bashford (2010) and Paul (2009). The word 'competition' has recovered and refined its intended sense within present-day biology and the improved version applies to the renewal of the theory of evolution by natural selection.

Contemporary definitions of competition are in agreement and can be found within the disciplines of evolutionary biology (e.g., Futuyma and Kirkpatrick, 2017) and ecology (e.g., Ricklefs, 1993), and in dictionaries of science (e.g, Lafferty and Rowe, 1993), biology (Lawrence, 2008) and ecology (Hine, 2019). Hine (2019) refers to competition as follows:

> 'The interaction between individuals of the same species (intraspecific competition), or between different species at the same trophic level, in which the growth and survival of one or all species or individuals is affected adversely. The competitive mechanism may be direct (active), as in allelopathy[86] and mutual inhibition[87], or indirect when a common resource is scarce. Competition leads either to the replacement of one species by another that has a competitive advantage, or to the modification of the interacting species by selective adaptation (whereby competition is minimized by small behavioural differences, e.g. in feeding patterns). Competition this favours the separation of closely related or otherwise similar species. Separation may be achieved spatially, temporally, or ecologically (i.e. by adaptations in behaviour, morphology, etc.). The tendency of species to separate in this way is known as the competitive exclusion or Gause principle[88].'

[86]Allelopathy is the suppression of growth of one plant species by another due to the release of toxic substances.

[87]Mutual inhibition is a form of direct competition between the populations of two species in which both species actively inhibit one another

[88]The competitive exclusion principle or Gause's law proposes that two species which compete for the same limited resource cannot coexist at constant population levels.

Hine (2019) could have used bacteriocins and the phenomenon of antibiosis as examples of direct or active competition between organisms. Bacteriocins are a group of proteins secreted by bacteria that kill or inhibit competing strains (Day, 1998) and which are used in food preservation Cleveland, 2001). Antibiosis refers to antagonistic associations among organisms in which one produces compounds, known as antibiotics, which are harmful to the other(s) (Lawrence, 2008). Antibiotics are pre-eminent in the treatment of bacterial infections in humans and animals (Aminov, 2010).

Odum (1983) makes three observations about competition that introduce notions of r-selection and k-selection. R-selection refers to selection favouring rapid rates of population increase and k-selection where species are selected according to their viability a stable environment.

1. Negative interactions tend to predominate in pioneer communities or in disturbed conditions where r-selection counteracts high mortality.
2. In the evolution and development of ecosystems, negative interactions tend to be minimized in favour of positive symbiosis that enhances the survival of the interacting species.
3. Recent or new associations are more likely to develop severe negative coactions that older associations.

4.3.6 Viruses and prions as life forms

Two mutually supportive perspectives on viruses and prions illuminate how the nature of these biological entities can be treated within the proposed ontology for the theory of evolution by natural selection. The first and operational perspective comes from biology and provides for knowledge and action across One Health. Emphasis is given to physiology which is described as the science of life and which seeks to illuminate the mechanisms of living things (https://www.physoc.org/explore-physiology/what-is-physiology/). Physiology provides the foundations of pathophysiology where disease is depicted as a manifestation of disordered function (Ganong, 2006) that can afflict all life forms and which operates in a gradient from health and vigour to poor health and disease. The biological perspective on viruses and prions aligns with microevolution rather than macroevolution, which has a subordinate and auxiliary role in biomedicine (Gluckman et al., 2017).

The second and foundational perspective comes from philosophy (particularly metaphysics), which is seen as ‘the study of the fundamental nature of knowledge, reality, and existence’ (Apple Dictionary, version 2.2.). This perspective aligns with macroevolution or evolution that occurs above the species level and which includes the origination, diversification, and extinction of species over long periods of evolutionary time (Zimmer and Emlen, 2016). The perspective from philosophy gives an all-round view of viruses that can support physiology at the ‘centre stage’ of evolutionary biology (Noble et al., 2014).

Recent discussions on the fundamental nature of viruses explore whether they are alive or not according to certain depictions of life (Farnsworth, 2021; Forterre, 2016; Harris and Hill, 2021: Nasir et al., 2020; Van Regenmortel, 2016). The species concept as it applies to viruses (Alimpiev,

2021; Bobay and Ochman, 2018; Domingo et al., 2021; Rybicki, 1990[89]; Van Regenmortel, 2020) has also been a subject of interest and requires comment.

Issues around the fundamental nature of viruses and the species concept provide entry to the behaviours, capabilities and epidemiological aspects of viruses that are relevant to the proposed ontology for the theory of evolution by natural selection and its intent to strengthen One Health. Foremost, is the question of whether viruses (and prions) are ‘life forms’, ‘organic beings, ‘live’ or ‘alive’, which has implications for implementing One Health. The history of the germ theory of disease and current biological conceptions of life argue that viruses and prions qualify unreservedly as life forms or organic beings. Viruses and prions are ‘live’ or ‘alive’ in their own idiosyncratic manner in the same way that monerans, protists, fungi, plants and animals are ‘live’ or ‘alive’ in their own idiosyncratic and distinctive manner. In short, the germ theory of disease plus the precepts of biology and physiology and processes of diagnostic reasoning and epidemiology can be informed by the theory of evolution by natural selection and applied unreservedly to the management of disease caused by viruses and prions. Metaphysical reflections on the nature of life and living systems should continue but are peripheral to the effective delivery of One Health, which has physiology and epidemiology as its integrating disciplines.

a. Germ theory and viruses and prions

The germ theory of disease and its timeline argues in favour of viruses and prions as life forms or organic beings. Three preliminary considerations set out a definitive background for the soundness of this argument. First is the crucial definition of Theory A (Science) as a ‘coherent statement or set of ideas that explains observed facts or phenomena and correctly predicts new facts or phenomena not previously observed’. Second is the idea of a ‘germ’ as an ‘element that can develop in the likeness of the form from which it sprang’ and so on (see Box 1, section 2.4.2). The word germ has a recent popular restriction to microorganisms that cause infectious diseases. The unintended consequence is to obscure the concepts of infection, infectious and infectious disease (see Glossary) and exclude macroscopic endoparasites and ectoparasites as agents of infection. These metazoa infect and may also infest in the sense of being present in large numbers[90].

Agencies involved in public health, such as the World Health Organization and the US Centers for Disease Control and Prevention, recognise that infectious diseases result from the presence and activity of infectious disease agents, which include biological entities (germs) such as prions, viruses, bacteria (monerans), protozoa (protistans), fungi and metazoan endoparasites and ectoparasites. Parasites that could be seen with the naked eye were recognised to have a role in particular diseases well before the emergence of microbiology and without links to miasmas and contagions (Farley 1989; Foster, 1965). Sources from the mid-nineteenth century that could be used to catalogue the role of metazoans in particular diseases are two treatises on the diseases of sheep (May, 1868; Youatt, 1838) and one on the diseases of horses (Youatt, 1843). As will be seen,

[89]Rybicki (1990) depicted viruses as ‘organisms at the edge of life’.

[90]An earlier exclusion of ‘higher organisms ‘such as parasitic worm or insects (Hoerr and Osol, 1956) is no longer tenable.

maturing concepts of causation exemplified by Evans' rules (Evans, 1976; see Thrusfield (1986) and Thrusfield and Christley, 2018) clearly identify metazoans as causative agents of infectious disease.

Merchant and Packer (1961) describe how the germ theory of disease came to be from the narrow viewpoint of microbiology and how and why this history affirms the nature of infectious agents as life forms, so-called germs, possessing the attributes that distinguish the animate from the inanimate. The work of Merchant and Packer is consistent with that of Bynum and Porter (1993), Porter (1996 and 1998) and Gaynes (2023) and allows for the following line of argument[91]. (1) Infectious diseases have characteristics and natural histories that require the possession and operation of the fundamental attributes of life by primary causative agents. (2) Some infectious diseases are caused by agents identified as viruses or prions. (3) Therefore, viruses and prions are life forms or organic entities which possess and operate fundamental attributes of life.

The history of knowledge about infectious diseases from the earliest observations to the present-day germ theory (Merchant and Packer, 1961) parallels the development of science with its processes of observation, reason and experiment/experimentation/trial (Feynman, 2011). The earliest, or prescientific, stage was dominated by the concept that infectious diseases were caused by supernatural magic or evil spirits (named as the 'theurgical "theory" of disease'). The theurgical theory (Theory B idea) of disease gave way to the miasmatic theory (Theory B idea) and the contagion theory (Theory B idea). This occurred when the observation and reason components of the science process flourished under the strong influence of Aristotle (384-322 BCE), 'the inventor of natural science' (Althoff, 2018).

The germ theory began to emerge when experimentation was made plain and advocated by scholars like Robert Grosseteste (1168-1253 CE), Roger Bacon (1214-1294 CE), and Francis Bacon (1561-1626 BCE) and completed the three processes of science as set out by Feynman (2011). Apparently, Aristotle who had a large impact of the development of science and its processes did not did not embrace experimentation as described by this excerpt from Gauch (2003):

> 'The greatest specific deficiency of Aristotle's science was profound disinterest in manipulating nature to carry out experiments. For Aristotle, genuine science concerned undisturbed nature, rather than dissected plants or manipulated rocks. Regrettably, his predilection to leave nature undisturbed greatly impeded the development of experimental science for a millennium and a half'.

Robert Grosseteste is said to have initiated a productive shift in science's emphasis, away from presuppositions and ancient authorities and toward empirical evidence, controlled experiments. and mathematical descriptions (Crombie, 1962). As to Roger Bacon, words from his Opus Maius are inscribed above the entrance to the Daubeny Building of Oxford's Botanic Garden: *Sine experientia nihil sufficienter sciri potest* (Sidebottom, 2013). *Experientia* is the central word and refers broadly to the testing of possibilities, trial, experiment (Oxford Latin Dictionary, 1968[92]). In his Novum

[91] *Modus ponens* inferences. If X implies Y, and X is true, then Y is true.

Organon, Francis Bacon emphasised the importance of experiments, tests, trials and empirical evidence.

The miasmatic theory (Theory B idea) attributed infectious diseases, other than those where causative agents could be observed directly, to miasmas or poisons in the air, exuded from rotting animal and vegetable material, the soil and standing water. In his 400 BCE treatise on air, waters and places (http://classics.mit.edu/Hippocrates/airwatpl.html). Hippocrates (460-370 BCE) pointed out how disease epidemics were related to wind direction, different waters and slope of the land (that is, topography). The miasmatic theory of disease was sufficient to launch major changes to public health practices in Britain and with a key input from Edward Chadwick (1800-1890 CE) (Porter, 1997). These changes included sewage removal systems and the cleansing of water. Action was accelerated by the 'Great Stink of London' in 1858 (https://en.wikipedia.org/wiki/Great_Stink).

Observation and reason were sufficient to instigate the contagion concept or theory (Theory A idea) of infectious disease and this foreshadowed the germ theory. Girolamo Fracastoro (1478-1553 CE) postulated that *seminaria* or seeds were the cause of epidemics of the black death, syphilis and typhus in people and foot and mouth disease in cattle (for references see Blancou, 2000). Contagion could occur by direct contact, through fomites or contaminated inanimate objects or at a distance. The words *seminaria* and seeds imply the involvement of a germ or living agent.
A move to the germ theory came when experimentation was fully embraced and transformed the understanding of living systems. As described by Merchant and Packer (1961), spontaneous generation was decisively refuted by the experiments of Francisco Redi (1626 -1693 CE), Louis Joblot (1647 – 1723 CE), Lazzaro Spallanzani (1729 -1799 CE) and Louis Pasteur (1822 – 1895 CE). Experiments by Theodore Schwann (1810 – 1882 CE) established that fermentation, decay and food spoilage were the result of microorganisms and not *vice versa*. Corroboration here came from experiments by Louis Pasteur (see Ullmann, 2024).

Foundations for experiments to launch the germ theory of disease were laid by Jacob Henle (1809 – 1885) in 1840[93] with a set of concepts that allowed for the Koch postulates. The Henle-Koch or Koch's postulates, in whatever form, can be viewed as a starting point for refined criteria that can accredit particular germs as the primary causative agent for particular infectious diseases extending to those caused by prions, viruses, bacteria (monerans), protozoa (protistans), fungi and metazoan endoparasites and exoparasites. Merchant and Packer (1961) set out a translation of the reasons put forward by Henle (1840) for attributing contagions to 'living organic beings'. These reasons form the basis of Koch's postulates, described by Gaynes (2023)[94] as follows: 1. The putative organism must be constantly present in diseased tissue. 2. The organism must be isolated in pure culture. 3. The pure culture must induce disease when injected into experimental animals.. 4. The same organism must be isolated from these diseased animals.

[92]Oxford Latin Dictionary (1968) Clarendon Press, Oxford (https://archive.org/details/aa.-vv.-oxford-latin-dictionary-1968/mode/2up).

[93]From Merchant and Packer (1961): Jacob Henle, *On Miasmata and Contagia*, 1840. Trans. George Rosen. John Hopkins Press, Baltimore. 1938, p. 19.

[94]Ascribed to Brock (1961).

Pioneering experiments during the late 19th and early 20th century used the Koch postulates to identify the bacteria involved a multitude of diseases commencing with the independent identification of *Bacillus anthracis* as the cause of anthrax by Robert Koch (b. 1843, d. 1910) and Louis Pasteur. The principal bacterial pathogens of 20 human disease were identified between 1877 and 1906 (Blevins and Bronze, 2010). Rivers (1937) points out some issues related to viruses and viral diseases and makes the following pithy statement, which serves to enlighten a path forward:

> 'To summarize, it can be said that the cause of viral diseases is known and that Koch's postulates as proposed by him do not have to be fulfilled in order to prove that a virus is the cause of a disease. However, the spirit of his rules of proof still holds in that a worker must demonstrate that a virus is not only associated with a disease but that it is actually the cause. The methods of doing this are different from the ones used by Koch but are equally efficient.'

Rivers (1937) highlights the essence of Koch's postulates as the necessity for rigour in the attribution of cause. In addition, Koch's postulates have been vehicle for progress according to the practice of science. Byrd and Segre (2016) state a need for continuing adaptation of Koch's postulates in order to maintain soundness and in the practice of science. Gradmann (2014) outlines some perceived issues with Koch's postulates..

Progress in the general area of disease causation is exemplified by the Hill's criteria. These are nine principles to guide the collection of evidence for a causal relationship between a putative cause and an observed effect (Hill, 1965). Progress in the area of infectious disease causation is exemplified by Evans' rules (Evans, 1974). Progress in the area of causation and causal inference across the whole One Health is exemplified by the conceptual framework provided by causal pies, sufficient cause and component causes (Rothman, 1976; Laake et al., 2004; Rothman and Greenland, 2005; Rothman et al., 2008; Thrusfield and Christley, 2018). Hill's criteria and Evans' rules have implications for the application of the proposed conceptual model or ontology for the theory of evolution by natural selection and are treated further in Appendix 4. Hill's criteria and Evans' rules align with causal reasoning which looks to cause-and-effect relations that can be understood by the analysis of structure and function in health and disease (Kassirer et al., 2009) and which can be standard practice across One Health.

In sum, considerations of the germ theory of infectious disease provide solid demonstration that viruses and prions are organic beings that possess the defining elements of life and can be treated as such within the proposed ontology for the theory of evolution by natural selection. Extension of Koch's postulates to prions is described by Walker at al (2006) and Deleault et al (2007).

b. The attributes of life and viruses and prions

Viruses and prions are part of the animate as opposed to the inanimate world. Viruses include the subsets of viroids and virusoids consist of RNA but lack a protein coat (Symons, 1991). Viruses and prions operate all characteristics of life that apply across the five kingdoms of cell-based life forms

(Whittaker, 1969) and the three domains of life (Woese et al., 1990) However, they do so in an idiosyncratic manner. The three principles governing life articulated by Nurse (2020) provide a useful perspective. The first of the three principles is the ability to evolve by natural selection. Since viruses and prions are able to evolve, they meet the first principle of life. Nurse's second principle is that life forms are bounded physical entities separated from but in communication with their environment. The third principle is that living entities are chemical, physical and informational machines that construct their own metabolism and use it to maintain themselves, grow and use it to maintain themselves, grow and reproduce. Viruses and prions meet these last two principles by means of symbiosis within host cells. They employ information encoded in their genomes to harness intracellular host-derived processes for transforming matter and energy. In this way, viruses and prions maintain themselves and reproduce and qualify as life forms or animate rather than inanimate objects. The definition of life with respect to the proposed ontology for the theory of evolution by natural selection was formulated in section 4.2.4 and is restated below in a form particular to viruses and prions.

> Sub-cellular life forms or organic beings exemplified by viruses and prions are entities with <u>capabilities for agency and the management, representation and processing of information</u> that allow them to manipulate the cellular machinery of prokaryotes and eukaryotes and thereby perform and exhibit the essential properties and characteristics of life, which are organisation and self regulation, metabolism, responsiveness, movement, growth, development, reproduction, life-cycling and evolutionary adaptation.

<u>c. A physiological perspective on viruses</u>

In biology, viruses are seen as submicroscopic infectious agents consisting of informational macromolecules (DNA or RNA in various forms that constitute a genome) enclosed in a protein coat (the capsid) and sometimes an outer lipoprotein envelope. Viruses are obligate intracellular symbionts. They complete the reproductive stage of their life cycles by employing information encoded in their genomes to harness processes within hosts for transforming matter and energy. In short, the genetic code for replication comes from viruses and host cells provide the necessary energy and matter. The generic term symbiont is more appropriate than the term parasite for present purposes (see section 4.3.5). On the whole, viruses are pathogens. However, there are observations that some viruses can benefit their hosts, mainly plants (Flint et al., 2015; Roossinck, 2011 and 2015; Roossinck and Bazan, 2017).

The physiology-focussed summation of a virus shown in Box 12 below will operate within the ontology for the theory of evolution by natural selection. It encompasses the viral life cycle, as proposed by Nasir et al. (2020). It can also extend to the idea that viral species are characterised by their capacity for gene exchange (Bobay and Ochman, 2018) and all without affecting the ICTV definition of a virus Koonin et al., 2021).

Box 12: A synopsis of the characteristics of viruses that will operate in the ontology for the theory of evolution by natural selection.

- Viruses are submicroscopic infectious agents, microbiological entities and obligate intracellular symbionts with life cycles entailing capabilities and structures for reproduction within hosts and transmission between hosts.
- The virion which consists of informational macromolecules (DNA or RNA in various forms that constitute a genome), a capsid or protein coat and sometimes an envelope or lipoprotein outer covering is the extracellular stage of viruses that mediates **infection** in hosts and **transmission** from host to host.
- Viruses reproduce within hosts by employing information encoded in their genomes to harness intracellular processes for transforming matter and energy.
- Viruses can have direct (monoxenous) life cycles when one host involved is and indirect (heteroxenous) life cycles when arthropod vectors are required for transmission between hosts.

The fact that viral populations change over time accords with the possession of genomes and the operation of life cycles. These properties qualify viruses for Darwin's 'descent with modification', which endures as a crisp summation of the phenomenon of evolution. Evolution involves processes of natural selection that act on factors or adaptations involved in fitness and by way of the genetic information and genetic mechanisms that determine diversity within a species, including viral species. The definition of an adaptation that suits present purposes is 'any peculiarity, property or feature of the structure, physiology or behaviour of an organism or biological entity, such as a virus or prion, that enables it to survive and reproduce in a particular environment'. The definition of fitness that suits present purposes is the 'success of an organism or biological entity, such as a virus or prion, at being viable and surviving and then contributing descendants to future generations'.

d. The species concept as it applies to viruses and prions

The definition of species for the proposed ontology for the theory of evolution by natural selection (see section 3.4.6) takes a strictly physiological perspective and depicts a species as a reproductively demarcated population of life forms. Demarcation of one species from another involves capabilities that implement and control the propagation and exchanges of genetic material as whole genomes through successive generations as described earlier. This reproductive perspective on a species readily extends to viruses where it can encompass the quasispecies proposal (Domingo et al., 2021) and cater for the broad definition of a virus species proposed by the International Committee on Taxonomy of Viruses (ICTV): *A species is the lowest taxonomic level in the hierarchy approved by the ICTV species is a monophyletic group of MGEs whose properties can be distinguished from those of other species by multiple criteria*[95].

The depiction of a species as a reproductively demarcated population of life forms also applies to prions. Prions, the causative agents of scrapie and the other transmissible spongiform encephalopathies, undergo change in response to evolutionary forces despite the absence of a nucleic acid genome (Li et al., 2010 and 2011; Adams, 2018 and 2020)). Inheritance in prions operates epigenetically; that is, through mechanisms other than the nucleotide sequences in RNA and DNA (Halfmann et al., 2012; Soto, 2011). Studies with chronic wasting disease (CWD), a transmissible spongiform encephalopathy of Nearctic deer, show that the primary structure or biochemical sequence of prion molecules determines the integrity of prion strains and their three dimensional structure. The consequence is that prion strains can change fundamentally when they

[95]The International Code of Virus Classification and Nomenclature (ICVCN), March 2021 (https://ictv.global/about/code)

move from host to host and have a primary structure that is determined by the prion gene of the new host (Angers et al., 2010).

e. Evolution, epidemiology and the population dynamics of disease caused by viruses and prions

The following synopsis of evolution in viruses and prions is directed explicitly to One Health and its needs. Experience with HIV-AIDS, SARS-CoV-1, COVID-19 (SARS-CoV-2), Mpox and new variants of influenza proclaim viruses as the pre-eminent agents of emerging and re-emerging infectious disease. Bovine spongiform encephalopathy (BSE) shows that prions can also be agents of emerging infectious disease. So-called microevolution rather than macroevolution is emphasised in this synopsis because it aligns with physiology and provides the depth of knowledge about evolutionary processes required for One Health. Microevolution refers to 'evolution occurring within populations, including adaptive and neutral changes in allele frequencies from one generation to the next' (Zimmer and Emlen, 2016) and represents what Mayr (1961) called functional biology as opposed to evolutionary biology which explores organisms as products of a history. Macroevolution looks to 'evolutionary processes extending through geological time, leading to the evolution of markedly different genera and higher taxa' (Lawrence, 2008). Accounts of evolution in viruses by Holmes (2002 and 2009) and Geoghegan and Holmes (2018 and 2021) extend to macroevolution and add a historical perspective (Mayr, 1961) that can broaden knowledge for One Health.

f. Evolution (descent with modification) in viruses

A text book on evolutionary biology (Smith, 1993) lists the drivers of evolution across all life forms as inheritance, variation and selection and captures the three-part gist of natural selection as stated in the last paragraph of *Origin of Species*. The three drivers of Smith (1993) correspond to Darwin's (1) 'inheritance which is almost implied by reproduction', (2) 'variability from the indirect and direct action of the conditions of life' and (3) 'Natural Selection, entailing Divergence of Character and the Extinction of less improved forms'. An understanding of inheritance, variation and selection in viruses and prions and their associations with concepts of fitness, adaptation and species is crucial to the proposed ontology for the theory of evolution by natural selection and can be guided by Figures 3, 4 and 5 and adherence to the chosen meaning of words as detailed in the glossary. Figure 3 shows the chain of transmission concept and locates where each of the elements of evolution (inheritance, variation and selection) operate within the life cycle of infectious disease agents such as viruses and prions. Figure 5 shows the epidemiological triangle and its counterpart in a proposed evolution triangle and its inspiration in the fire triangle. The epidemiological triangle in Figures 5 and 6, like the chain of transmission in Figure 3, displays interactions among hosts and the sources of heritable variation and diversity in disease agents like viruses. The evolution triangle shows how similar interactions between the environment, disease agents and hosts provide for selection, coevolutionand disease emergence.

The chain of transmission or chain of infection concept (Bhopal, 2002; CDC, 2006; van Seventer and Hochberg, 2017) in Figure 3 depicts the life cycle of an infectious agent like a virus or prion as six links in a chain. Transmission rather than infection is the preferred term here because it distinguishes the transfer of a disease agent to a host. Infection is suitably restricted to the processes of invasion and the disease caused by the infectious agent. The six elements in the chain of transmission help to identify where and when the processes of inheritance, variation and selection operate for viruses and prions. These elements or links are elaborated in the excerpt from van Seventer and Hochberg (2017) shown below.

> 'The chain starts with the infectious agent (link 1) residing and multiplying in some natural reservoir (link 2); a human, animal, or part of the environment such as soil or water that supports the existence of the infectious agent in nature. The infectious agent leaves the reservoir via a portal of exit (link 3) and, using some mode of transmission (link 4), moves to reach a portal of entry (link 5) into a susceptible host (link 6). A thorough understanding of the chain of infection is crucial for the prevention and control of any infectious disease, as breaking a link anywhere along the chain will stop transmission of the infectious agent.'

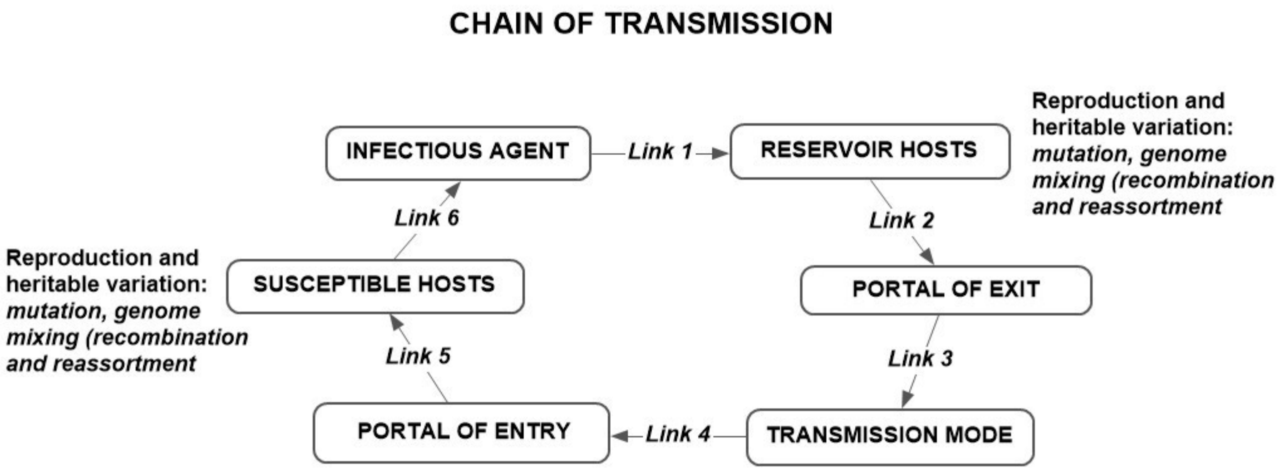

Figure 3: Diagram showing the chain of transmission to give a perspective on the circumstances that allow for coevolution in hosts and infectious disease agents. The chain of transmission identifies where interactions among hosts and infectious disease agents give rise to heritable variation and diversity. Sites for genome mixing (recombination and re-assortment) by means of mixing vessel hosts are identified.

Selection, the third of the three processes in natural selection results from an interplay between hosts, disease agents and the environment. To reiterate, selection works through a means likened to a passive filter where selection acts upon fitness (viability) and its associated adaptations (see section 3.3.4). Fitness founded upon viability and followed by reproductive success applies to viruses and prions as pathogens of interest within One Health. Viability and its mediation by adaptations or capabilities in viruses and prions as pathogens must be effective at each step in the chain of transmission and must operate sequentially from portals of exit in infected host to portals

of entry in susceptible hosts. Unfit (unviable) variants from one cycle of life can not reproduce and will be absent the next cycle of life. Unfit variants disappear as pathogens. Transmission based on appropriate adaptations in viable or fit viruses and prions can occur prenatally, postnatally or both and multiple portals of entry may operate.

Variation and inheritance operate as a unit as highlighted in the last paragraph of *Origin of Species*, and appear twice under the heading of 'reproduction and heritable variation' in Figure 3. Links to susceptible and reservoir hosts are shown in Figure3, which are sites for mutation and genome mixing by recombination and re-assortment within the informational macromolecules of viruses.

Knowledge about the causes, opportunities and mechanisms of variation and inheritance that arise from interactions between hosts, infectious agents and the environment can expedite and systematise investigations into disease emergence and can guide the design of countermeasures and programs for pathogen prioritisation (see FAO, 2013a; Fauci and Volkers, 2023; and WHO[96]). Mechanisms driving variation and inheritance in viruses are mutation rates, which differ enormously across viral species and tendencies and opportunities for genome mixing through recombination and re-assortment of genomes within populations of viral species. Mutation refers to alterations from whatever cause in the genetic material constituting the genome of an individual. Genome mixing refers to genetic alterations that occur when different genomes are blended. Genome mixing occurs in environments that provide opportunities for contact and interactions among various types of hosts and various sub-populations of viral species with different host ranges. These environmental opportunities are depicted in both the epidemiological triangle and the evolution triangle and can be tracked down by direct and indirect examination of the environment which stands as an essential component of disease and other investigations (Blood and Henderson, 1963; Cook et al., 2013).

The following consideration of mutation rates, tendencies and opportunities for genomic recombination and re-assortment in different classes of viruses has been assembled from five contemporary textbooks on virology (Burrell et al., 2017; Dimmock et al., 2016; Flint et al., (2015); Howley and Knipe, 2021; McLachlan and Dubovi, 2017) and elsewhere (Holmes 2002 and 2022; Peck and Lauring, 2018). The host-virus association is fundamental to the processes of reciprocal evolution and requires a complementary overview of the nature of hosts.

Mutation rates within genomes and tendencies for genome mixing in viruses vary according to the nature of informational macromolecules. The Baltimore classification (Baltimore, 1971), which has developed over time, categorises viruses according to their genome type (see Table 12) and can forecast the characteristics of reproduction and heritable variation in a given virus from the nature of its genome.

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[96]Pathogens prioritization: a scientific framework for epidemic and pandemic research preparedness
30 July 2024, Meeting report (https://www.who.int/publications/m/item/pathogens-prioritization-a-scientific-framework-for-epidemic-and-pandemic-research-preparedness)

Table 12. Baltimore classification system for viruses based on the nature of their informational macromolecules and manner of messenger RNA synthesis.

Class of virus	**Genome characteristics and representative examples**
1	Double-stranded DNA viruses such as the mpox and smallpox viruses.
2	Single-stranded DNA viruses such as the feline panleukopenia parvovirus and the canine parvovirus,
3	Double-stranded RNA viruses such as the bluetongue virus and the infectious bursal disease virus,
4	Positive sense single-stranded RNA viruses such as coronaviruses and the foot and mouth disease virus,
5	Negative sense single-stranded RNA viruses such as influenza viruses and rabies virus,
6	Single-stranded RNA viruses with a DNA intermediate in their life cycle such as human HIV viruses and the maedi-visna virus.
7	Double-stranded DNA viruses with an RNA intermediate in their life cycle such as the hepatitis B virus.

Replication in viruses with DNA genomes is accurate and occurs through DNA polymerase which has proofreading capabilities (Reha-Krantz, 2010). Mutation rates in these viruses are similar to bacteria with about 0.003 mutations per genome, per replication (Holmes, 2002). By contrast, replication in viruses with RNA genomes is error prone because proof-reading mechanisms are absent from the RNA-dependent RNA-polymerases (RdRp) that govern genome replication in these life forms (Choi, 2012). As a consequence, mutation rates in RNA viruses (including retroviruses) are inordinately higher than those in DNA viruses. Dimmock et al. (2016) state that an RNA virus can achieve in one generation the degree of genetic variation which would take an equivalent DNA genome between 300,000 and 3000,000 generations to achieve. Overall, single-stranded viruses tend to mutate more rapidly than double-stranded viruses. However, a number of single-stranded DNA (ssDNA) viruses have rates of mutation similar in to those of double-stranded RNA (dsRNA) viruses and several DNA viruses exhibit evolutionary rates comparable to those of RNA viruses (Peck and Lauring, 2018). High levels of genetic diversity generated by high rates mutation and exposure to natural selection have a powerful impact on the emergence of viral diseases, especially those cause by single-stranded RNA viruses.

The second powerful factor in viral evolution that drives the emergence of new disease-causing variants is genome mixing by means of recombination and re-assortment. Genome mixing is the phenomenon whereby informational macromolecules (DNA or RNA) from two or more individual genomes split and then recombine to form new genes or allele combinations. In eukaryotes, homologous recombination occurs at regions of sequence similarity during meiosis and gamete formation. Recombination also occurs at non-homologous sites in somatic cells by means of

transposons or mobile genetic elements that can move between positions in the one genome. In prokaryotes, recombination is a mechanism for horizontal gene transfer whereby free extracellular DNA is integrated into genomes by means of transformation (the uptake of free or naked DNA present in the environment), transduction (which involves a viral vector) and conjugation (where one prokaryote receives DNA from another prokaryote via cell surface organelles). Recombination occurs in viruses when more than one viral genome from the same viral species, or reproductively demarcated population (see section 4.3.6d), is present in the same host. The result is an increase in diversity and a new population that can be selected for fitness, including capabilities for causing disease.

The potency of recombination in driving viral evolution in single-stranded RNA viruses has been amply demonstrated with coronaviruses (Amoutzias et al, 2022; Guo et al, 2024; Rochman et al, 2022; Su et al, 2016) and influenza viruses (Causey and Scott, 2008). Recombination also operates in the evolution of double-stranded RNA viruses such as that causing infectious bursal disease in chickens (Gao et al, 2023) and retroviruses such as HIV-1 and HIV-2 (Delviks-Frankenberry, 2011). There is evidence that single stranded DNA viruses may recombine with host dsDNA but recombination with other single stranded RNA viruses is not mentioned (Stedman, 2015). Tendencies for recombination operated in double stranded DNA viruses and particularly in the poxviruses (Alakunle et al 2020; Brennan et al, 2023; Evans et al, 2022; Sprygin et al, 2022).

Reassortment, like recombination, is a form of exchange of genetic material within a viral species that leads to variants new capabilities. Reassortment is a version of recombination that is conspicuous in negative-sense single-stranded RNA viruses with segmented genomes and refers to recombination between segments. Reassortment can also occur in double-stranded RNA viruses and is rare in positive-sense single stranded RNA viruses. Reassortment becomes possible when two or more variants of the same species infect the same cell simultaneously and is instrumental in the evolution and emergence of new forms of epidemiologically important viral diseases such as influenza. Antigenic shift applies in discussions of influenza A and refers to the formation of antigenically novel surface glycoproteins by means of genome re-assortment.

Viral diseases caused by negative-sense single stranded RNA viruses and influenced by reassortment include orthomyxoviruses with influenza A, B and C (Abdelwhab and Mittenleiter, 2023; Webster, 2023), bunyaviruses with Rift Valley fever (Balaraman et al, 2024) and Crimean-Congo haemorrhagic fever (Zhou et al., 2013 and arenaviruses with Lassa fever (Moschkoff et al., 2007). Viral diseases caused by double-stranded RNA viruses and influenced by reassortment include rotaviruses and the associated gastroenteritis in people and livestock (Tian et al, 2022) and reoviruses with bluetongue in ruminants (Sanders et al, 2022).

Hosts and their nature are an essential factor in the evolution and emergence of viral diseases. New manifestations of viral diseases come about in two ways. First is when pre-existing forms in permissive hosts transform and infect previously non-permissive hosts and create new permissive and reservoir host. Second is when pre-existing forms of a viral disease in their usual host change in

their virulence or pathogenicity or both. Both pathways can operate simultaneously and both depend upon mutation and genome mixing or both. To explain, permissive hosts are those possessing cells in which replication of a particular virus species can take place. Non-permissive hosts are those that do not possess cells in which replication of a particular virus species can not take place. Reservoir hosts are those which a given pathogen usually dwells and is maintained as source of infection to other host species. Reservoir hosts represent harbours for particular pathogens. Maintenance host and definitive hosts correspond with reservoir hosts.

Genome mixing requires hosts that can be infected simultaneous with two or more variants of the same viral species. Such hosts are named as bridge hosts (Caron et al., 2014 and 2015) or mixing vessel hosts (Scholtissek, 1987; Yasuda, 1991; Abdelwhab and Mittenleiter, 2023). The following extract from Scholtissek (1987) explains the idea of mixing vessel or bridge hosts in an article on influenza: 'The age-old agricultural techniques practised in South China, where humans, pigs and ducks live always in close contact, might explain why all human influenza virus pandemics start from that region. The pigs seem to be the "mixing vessels", where the new pandemic strains were created'. In short, mixing vessels hosts are those that can be infected simultaneously with more than one subpopulation of a viral species and where horizontal transfer of genetic information between subpopulations can occur and generate new viral subpopulations with new capabilities. New capabilities extend to host range, pathogenesis, virulence, infectivity, routes of transmission, portals of exit, portals of entry and survival time in the environment and can increase pandemic potential. Bridge hosts are those that provide a link through which pathogens can be transmitted from maintenance host populations or communities to receptive populations that require protection. Management of epidemics and pandemics of viral disease is complicated by the fact that bridge hosts and mixing vessel hosts can be asymptomatic carriers of viral infections (Furuya-Kanamori et al., 2016; National Biosecurity Committee [Australia], 2025; Parasher, 2021; Reed et al, 2003; Wildlife Health Australia, 2005;).

The precising definition of a species developed for the proposed ontology for evolution theory is crucial to a understanding of mutation by genome mixing. To reiterate from the Glossary, species are discrete populations of life forms possessing communal properties for reproduction or reproductively singular populations of life forms.

g. Evolution (descent with modification) in prions

As to prions and evolution, prions are the causative agents of the transmissible spongiform encephalopathies and prions as infectious proteins are now implicated in many other neurodegenerative disorders (Walker and Jucker, 2015). Observations of strain behaviour and experimental demonstrations of natural selection in progress establish that prions in general possess the functions for variation, reproduction and heritability that allow for selection and drive evolution (Adams, 2018 and 2020, Halfmann and Lindquist, 2010; Li et al, 2010 and 2012; Weissmann, 2012). Accordingly, prions qualify as evolvable and objects of selection (Brookfield, 2009;

Kirschner and Gerhart, 1998; Lewontin, 1970). Prions thus fit within the scope of the proposed ontology for the theory of evolution by natural selection.

4.4 Diagrams as a way towards renewing the theory of evolution by natural selection for practice in One Health

Diagrams are visual presentations of information that help clarify, simplify and illustrate complex ideas (Braigrie, 1996; Eddy, 2020) and expedite intelligible communication. They include flowcharts, graphs, Venn diagrams, concept maps, block diagrams and conceptual frameworks that work by showing how different elements in a matter of interest mesh. In doing so, diagrams and the related idea of a schema make complex relationships more intelligible. Diagrams and written texts complement one another to make communication more effective. Diagrams provide reference points that make the written text more accessible and illuminating, give the written text context and provide explanations that augment the written text:'a picture speaks a thousand words'. Diagrams have been employed within the present endeavour as a means for identifying issues, guiding literature searches and marshalling information and ideas as a preparation for writing and then as a resource for reflecting on the written text and reviewing its coverage and lucidity. Preliminary diagrams of this sort that outline issues, considerations and implications have a role elsewhere; for example, in the preparation of risk assessments, situation reports and policy advice notes.

Ontologies used in information technology and artificial intelligence qualify as diagrams as does the ontology proposed for the evolution theory, which will be assisted by a concept hierarchy. Precedents for organising and assembling this ontology come from diagrams of the fire triangle, the epidemiological triangle and from triangles proposed for germ theory and evolution theory. These diagrams can unify and coordinate cell theory, germ theory and evolution theory and enhance their implementation in One Health. They are constructive background to the ontology for evolution theory.

Figure 2 (section 4.1.1) initiates the process towards an ontology for evolution theory by extending upon a broad overview of the life sciences put forward in a biology textbook by Campbell and Reece (2002) and based on two dimensions. The vertical dimension deals with biological organisation and implies cell theory. The horizontal dimension attends to biological diversity and the unity of life and implies evolution theory. An additional diagonal dimension is proposed to cater for biological associations and germ theory and to show how cell theory, evolution theory and germ theory can align for application in One Health. The new version of Campbell and Reece's panorama of the life sciences echoes the epidemiological triangle or triad (Snieszko, Mausner and Kramer, 1985; Timmreck, 2002; Bhopal, 2002; Nelson et al., 2005; Centers for Disease Control, 2012; van Seventer and Hochberg, 2017), which illuminates disease causation by showing the three-way relationships among the host, the environment and the disease agent or condition. In doing so, the scene is set for the sequence of diagrams that move stepwise to the ontology for evolution theory, as expounded in Chapter 5 and assisted by precising definitions for its structure, concepts and substance.

Figure 4 is first in this sequence of diagrams and was prompted by fire triangle used as a model for informing defence against the hazard of fires and the epidemiology triangle used as a model for informing the management to infectious and non-infectious diseases. It shows the fire triangle and the epidemiology triangle and equivalent triangles for the germ theory disease and evolution theory. Details in the fire triangle were extracted from the bushfire website of CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia, at https://research.csiro.au/bushfire/.

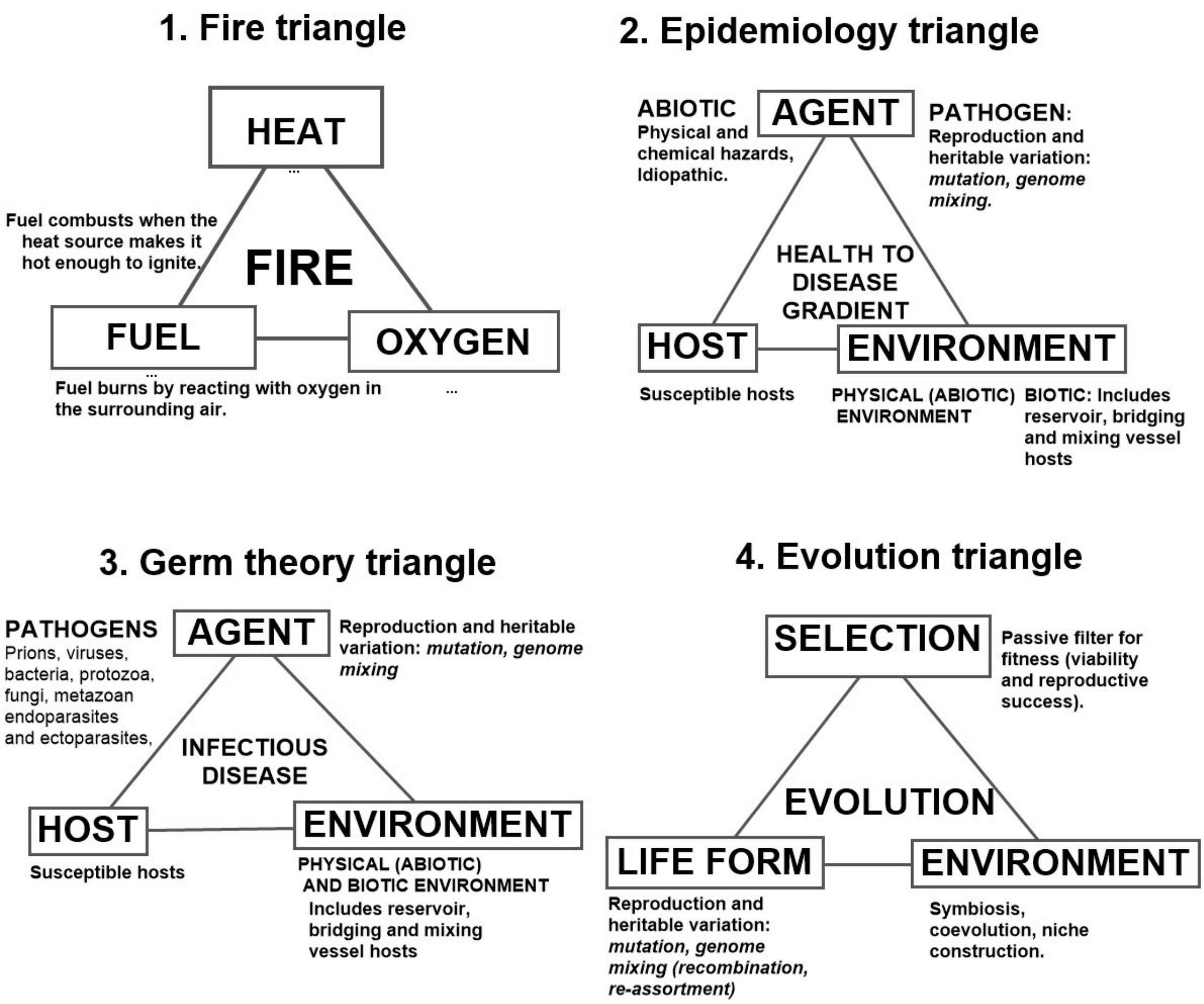

Figure 4: Four diagrams showing outlines of the fire triangle, the epidemiological triangle and prototype triangles for germ theory and evolution theory. The epidemiology triangle displays interactions among hosts and the sources of heritable variation and diversity in disease agents like viruses. Sites for genome mixing and mixing vessel hosts are identified. The triangle for germ theory echoes that for epidemiology except that it deals only with infectious disease. The triangle for evolution theory shows interactions between life forms and disease agents as the basis for selection and subsequent co-evolution.

Similarities between the epidemiology triangle and the triangles for germ theory and evolution theory are conspicuous and of primary importance. All three concern interactions between life forms, the environment and an agent or agency, defined as the thing that produces a specified effect. The triangles shown in abridged form in Figure 4 are elaborated on in the following sections.

4.4.1. Fire triangle

Risk factors for the fire triangle shown in detailed form in Figure 5 derive from the notion that fuel combusts when a heat source makes it hot enough to ignite. Heat sources at the apex of the triangle can be natural as in lightning strikes or result from human activity such as poorly managed campfires, damaged electricity powerlines, sparks from power tools and arson. Fuel, at the bottom left vertex of the triangle, burns by reacting with oxygen in the surrounding air to release more heat and to generate embers that spread the fire to other sites. High airflows increase fire intensity and the spread of embers. Fuel sources shown in the can be rural such as forests, grasslands, farmlands and other types of vegetation or urban such as combustible fuel (motor vehicles etc.), wood and rubbish heaps, stored inflammable liquids and solids, gas cylinders, sheds and houses, trees and other vegetation.

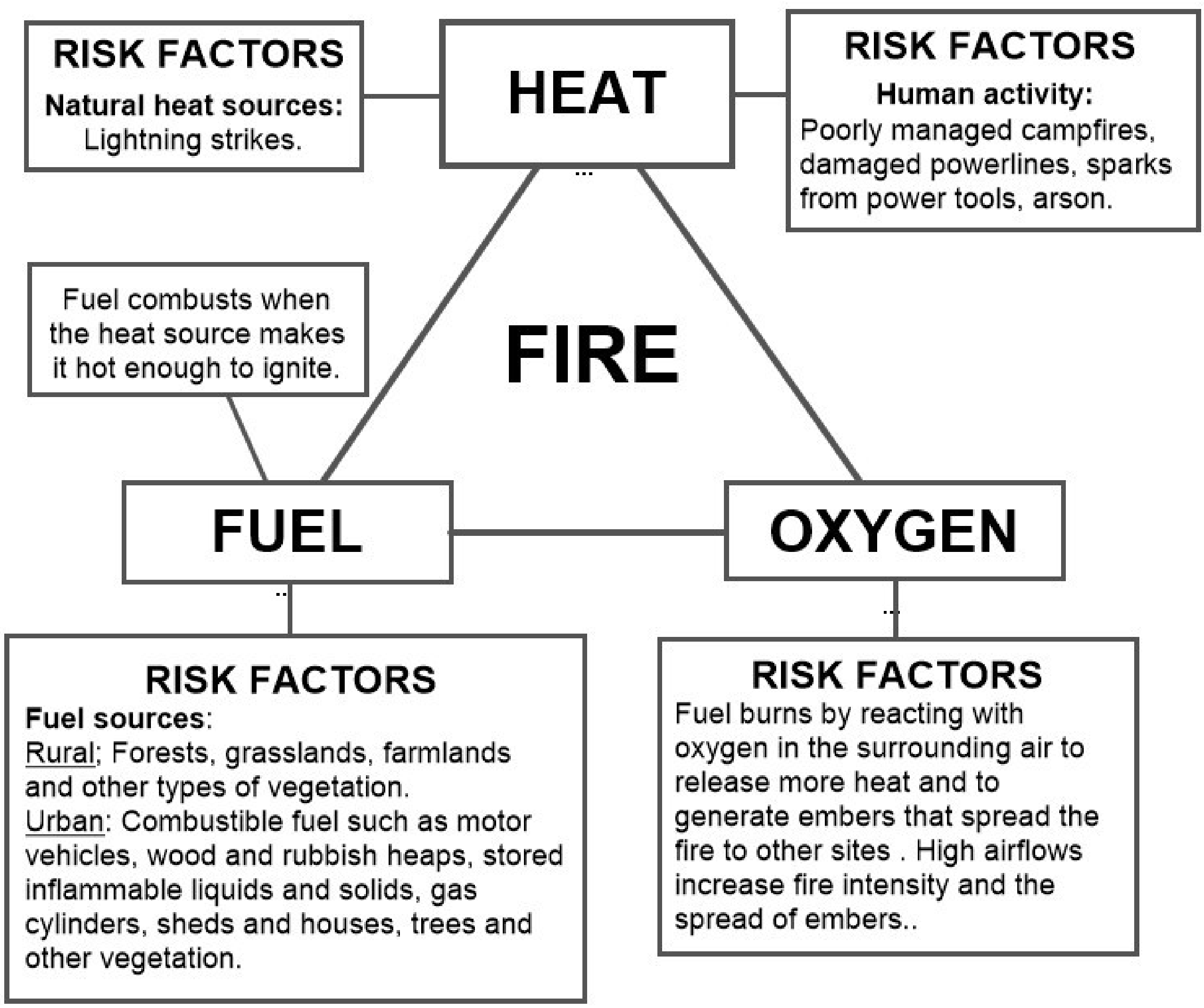

Figure 5: Detailed version of the fire triangle shown in Figure 4.

4.4.2. Epidemiological triangle

The epidemiological triangle or triad, which was intimated by McNew in 1970 (Scholthof, 2007 and 2024) and subsequently explicated by Snieszko in 1974 (van Seventer and Hochberg, 2017), gives graphic form to how health and disease in life forms arises from three-way interactions with their environment (Darwin's 'conditions of life') and the agents of infectious and non infectious disease. The epidemiological triangle is missing from many textbooks on epidemiology (for example Rothman et al. 2008; Thrusfield 1985; Thrusfield and Christley 2018; Celentano and Szylko, 2019) but given prominence in others (for example Mausner and Kramer, 1985; Timmreck, 2002; Bhopal, 2002; Nelson et al., 2005). The Centers for Disease Control (2012) promote the epidemiological triangle as a simple model for identifying the factors in disease occurrence and Liu et al (2023) have extended it to create a 'triangle model' theory for preventing and controlling newly emerging infectious diseases in China. The epidemiology triangle provides an exceptional opportunity and means for marshalling knowledge about the factors and circumstances involved in the health and disease of life forms that can inform One Health. The three way interactions, which operate among life forms, their environment and infectious disease agents in the case of germ theory or the agency of natural selection in the case of evolution theory infer that these two theories can be illuminated by triangles analogous to the epidemiology triangle.

Details within the epidemiological triangle were informed by several accounts (Bhopal, 2002;) and augmented by general reading. Details for the triangles for germ theory and evolution theory came from the contents of the present endeavour and were similarly augmented by general reading. A detailed version of the epidemiological triangle is shown in Figure 6. It represents how infectious diseases, and non-infectious diseases, result from an interplay between the disease-bearer (the host), the disease-agent (viruseswererserw etc) and their common surroundings (the environment). Diseases, depicted at the interior of the triangle, operate through a gradient that ranges from vigour to health, ill-health and then to disease The agents of disease are depicted at the apex of the triangle. Pathogens such as prions, viruses, bacteria, protozoa, fungi and metazoan endoparasites and ectoparasites are the agents for infectious diseases. Physical and chemical hazards such as poisons, radiation, mechanical forces, malnutrition, under-nutrition, air and water quality are agents for non-infectious diseases. Hazards are undefined for idiopathic diseases which have no explicit external causative agent.

Host factors operating in the epidemiological triangle have three sources. First is the physical state or constitution of the host and include matter such as immune status, age, nutritional status, microbiome composition. Second is genotype and predispositions for susceptibility to infectious disease and the severity of disease. Third is the behaviour of hosts related to sanitation, hygiene, dietary preferences, activities that heighten exposure to disease agents, population densities and maladaptive activities.

Factors in the physical or abiotic environment and the biotic or biological environment of hosts or disease-bearers operate in the epidemiological triangle. The physical environment includes climate, weather, temperature and rainfall affecting the abundance of pathogens and the presence of other hazards such as air and water quality. Factors in the biotic environment can be listed as the presence of disease vectors and pathogen reservoirs, processes leading to emergence of virus variants. These processes include contact between multiple permissive hosts and genome mixing through mixing vessel hosts and contact with vectors allowing spillovers to new species and places. Factors in the social environment straddle the abiotic and biotic environment of disease-bearers and include population densities and migration, nutritional and other customs and anthropogenic impacts such as deforestation and habitat destruction, heat islands, unsustainable resource usage, agricultural practices like antibiotic use and climate change.

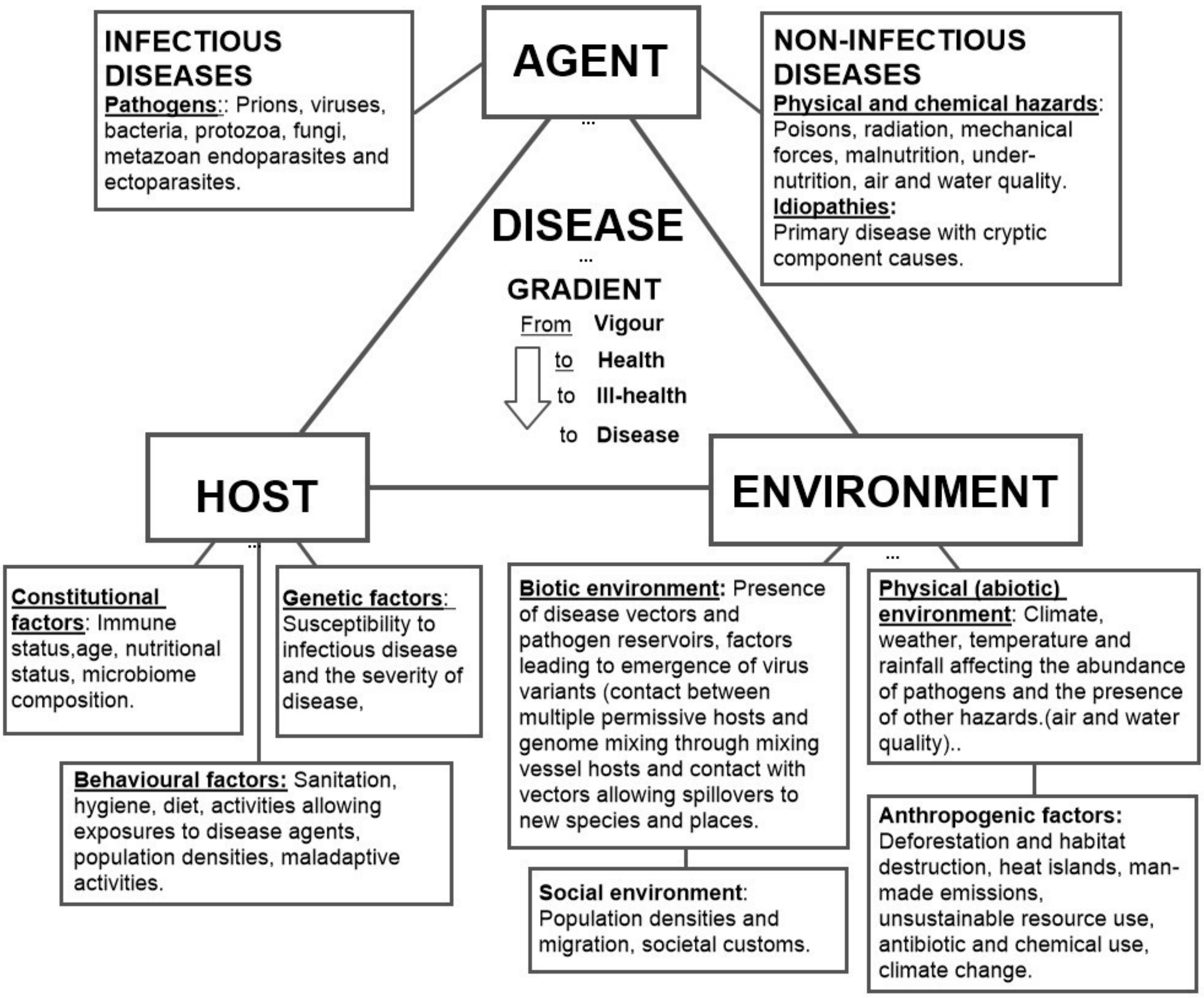

Figure 6. Detailed version of the epidemiological triangle shown in Figure 4.

4.4.3. A triangle for germ theory

A detailed version of the triangle for germ theory is shown in Figure 7. It builds on the epidemiology triangle but refers only to infectious disease and shows how these diseases result from an interplay between the disease-bearer (the host) and the pathogen (the disease agent) and their common surroundings (the environment). Pathogens such as prions, viruses, bacteria, protozoa, fungi and metazoan endoparasites and ectoparasites are the agents for infectious diseases.

Host factors operating in the triangle for germ theory are the same as those operating in the epidemiological triangle and have three sources. First is the physical state or constitution of the host and include matter such as immune status, age, nutritional status, microbiome composition. Second is genotype and predispositions for susceptibility to infectious disease and the severity of disease. Third is the behaviour of hosts related to sanitation, hygiene, dietary preferences, activities that heighten exposure to disease agents, population densities and maladaptive activities.

Factors in the physical or abiotic environment and the biotic or biological environment of hosts or disease-bearers that operate in the epidemiological triangle are repeated in the triangle for germ theory. The physical environment includes climate, weather, temperature and rainfall affecting the abundance of pathogens and the presence of other hazards such as air and water quality, which can affect host susceptibility. Factors in the biotic environment can be listed as the presence of disease vectors and pathogen reservoirs. Processes leading to emergence of virus variants are specially important. These processes include contact between multiple permissive hosts and genome mixing through mixing vessel hosts and contact with vectors allowing spillovers to new species and places.

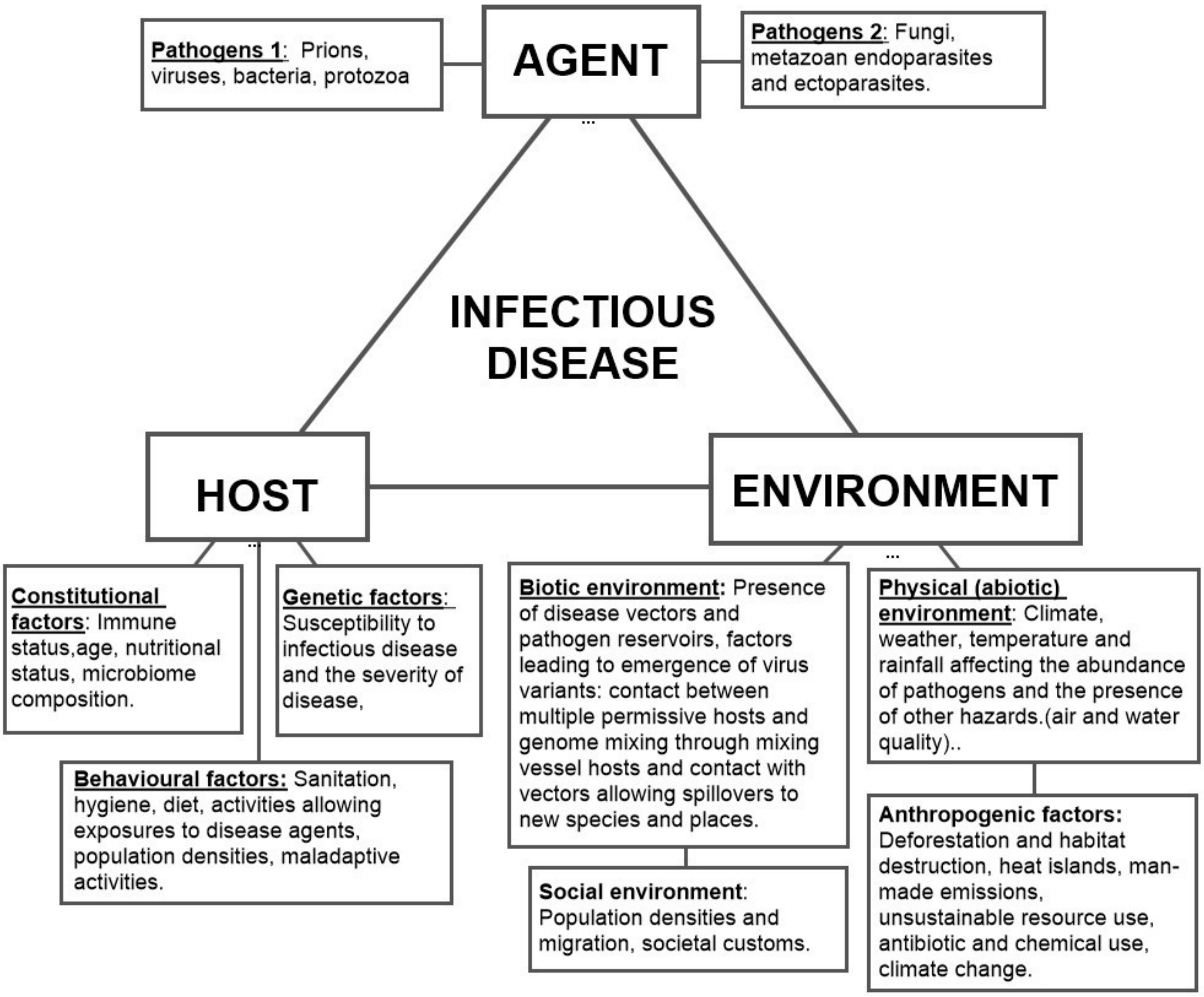

Figure 7. Detailed version of the triangle for germ theory shown in Figure 4

4.4.4. A triangle for evolution theory

A detailed version of the triangle for evolution theory is shown in Figure 7. The triangle is a prelude to the ontology assembled in Chapter 5 as a means for renewing of the theory of evolution by natural selection (evolution theory) that can optimise its application in the One Health and assist with foresight about emerging infectious diseases. Darwin (1859 – 1872) described the drivers of evolution through natural selection as the ‘laws acting around us’ which is restated the ‘factors acting around us’ to follow the contemporary meanings of laws and theories in science.. These drivers operate at the bottom vertices of the triangle according to the Nature A (Essence) of the life form and Nature A (Essence) of the environment. Darwin’s drivers of evolution are (1) growth with

reproduction, (2) inheritance which is almost implied by reproduction and (3) variability from the indirect and direct action of the external conditions of life (the environment).

The theory of evolution by natural selection (evolution theory) in terms of Theory A (Science) explains the unity and diversity of life (Campbell and Reece, 2002). It is predicated upon the precising definition developed for life that covers all life forms including viruses and prions. Like all theories, evolution theory can 'make definite predictions about the results of future observations' (Hawking, 1988). The phenomenon of evolution or Darwin's 'descent with modification' is the subject of evolution theory and is shown at the interior of the triangle in Figure 7. Here it links to precising definitions for the phenomenon of evolution itself and the associated coevolution and then passes to the capabilities that operate as Darwin's drivers of evolution. Evolution refers to changes within populations of life forms (including viruses and prions) over generations. Coevolution refers to reciprocal evolution in interacting species in ecosystems where changes in one species affect evolution in other species.

The apex of the triangle for evolution theory is the site for agency or that by which something is done. This agency is natural selection where natural has the sense of Nature A (Essence). There are links to boxes with precising definitions and explanations of causal processes. Natural selection is the process that impels evolution and occurs where life forms interact with their environment according to their nature and the nature of their environment and its biotic and abiotic elements. The environment and its nature are Darwin's 'external conditions of life'. Natural selection acts as a passive filter on populations of species through capabilities for viability and reproduction that pair as fitness. The consequence is the intergenerational elimination of variants of a species with inadequate fitness. A precising definition for species is crucial. Species are denoted as life forms that are demarcated as separate or singular populations through mechanisms that delimit reproduction and interbreeding.

The two vertices at the base of the triangle for evolution theory are sites for the nature of the life form and the nature of the environment (Darwin's 'conditions of life'). Elements in these two sites constitute what has been termed the causation unit that makes up the final subordinate concepts in the proposed ontology for evolution theory. These elements and their precising definitions and explanations are elaborated in Chapter 5 where the ontology is assembled.

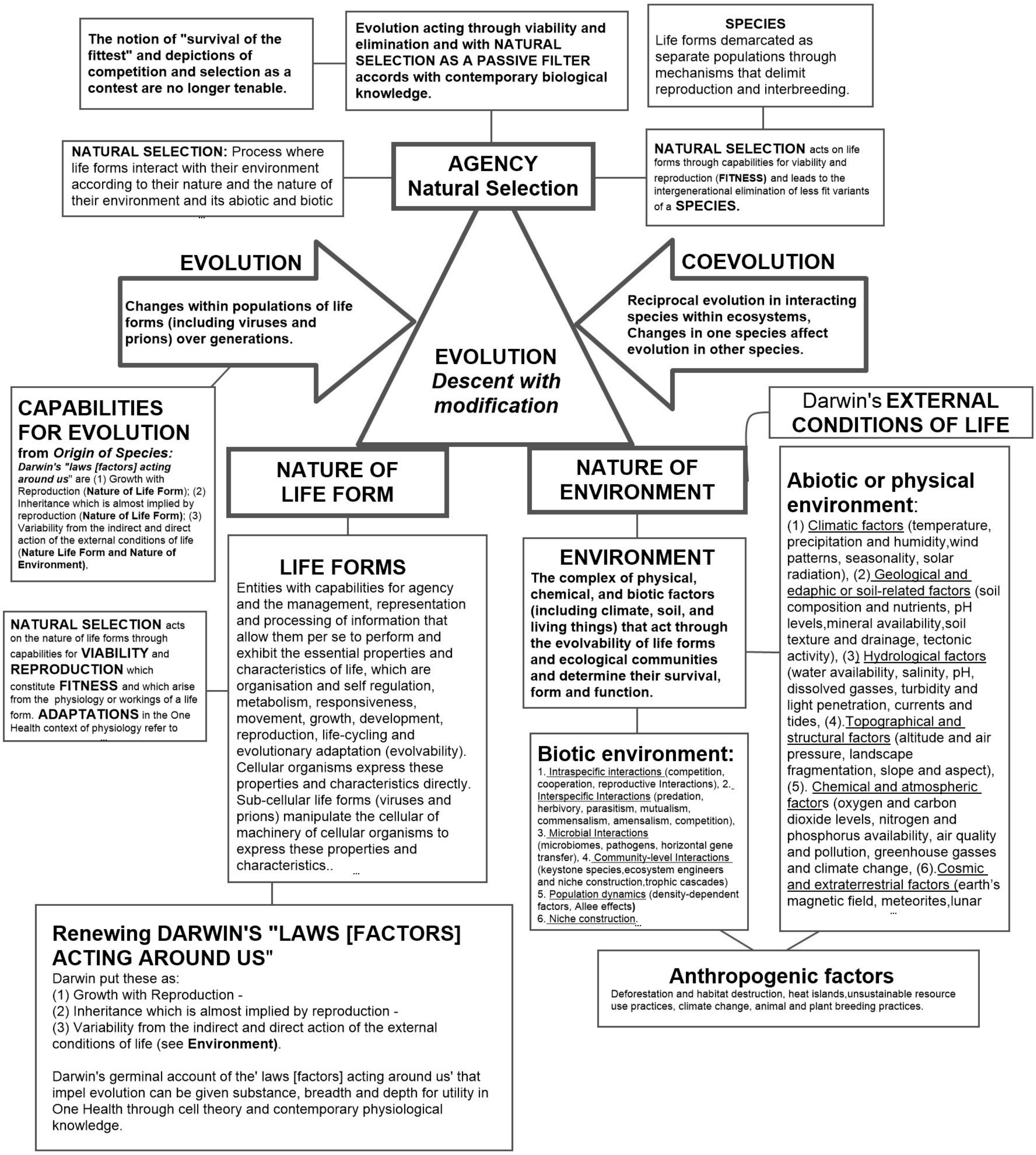

Figure 8: Detailed version of the prototype evolution triangle shown in abridged form in Figure 4.

Chapter 5. Renewal of Evolution Theory for One Health by Means of an Ontology

The title of this work on renewing theory of evolution by natural selection for universal application within One Health contains the word ‘renew’ and the phrase ‘one long argument’, which comes from the opening sentence in the last Chapter in all editions of *Origin of Species*. Darwin states that ‘as this whole volume is one long argument, it may be convenient to the reader to have the leading facts and inferences briefly recapitulated’. Darwin’s example is followed and matters inspiring, guiding and shaping the present renewal will be ‘briefly recapitulated’ before assembling the ontology or type of conceptual framework for theory of evolution by natural selection from its explicitly defined component parts. Recapitulation covers matters raised under the headings of setting the scene (Chapter 2), the historical context for a renewed version of the theory of evolution by natural selection (Chapter 3) and pathways to renewed version of the theory of evolution by natural selection (Chapter 4). Recapitulation of these various interrelated matters is preceded by some thoughts about the word ‘renew’ which shapes the present effort.

5.1 Why renew theory of evolution by natural selection?

To renew means to bring up to date and give a perspective on theory of evolution by natural selection (evolution theory) that can assist the effective delivery of One Health and its aim of advancing the common good. Renewing entails a present-day understanding of the essence and ramifications of evolution theory and a way forward comes from the arrival of information technology (IT) in the last quarter of the twentieth century and its profound impact on scholarship and the practices and application of science (Roberts and Westad, 2013). For example, components of IT (artificial intelligence and knowledge engineering) have been used to predict the tertiary structure of proteins (Jumper et al, 2021; Wuyun et al, 2024). This IT guided renewal is based on the contention that the fundamentals of evolution theory were presciently and demonstrably captured by Darwin in *Origin of Species* and were subsequently reiterated by Wallace (1889). Another guiding factor is that theories, in the sense defined for science, provide landmarks for old and new knowledge and require continual refinement in order to maintain their usefulness.

Darwin’s consideration of variation under domestication (Chapter 1 of *Origin of Species* with its references to plant and animal breeding constitute potent experimental evidence for the evolution theory and place it with cell theory and germ theory as one of the three overarching theories that inform the life sciences. A present-day understanding of evolution theory suited to the values of One Health and its need for practical wisdom (‘phronesis’) derived from facts (‘episteme’) and skill (‘techne’)(Abbasi, 2011) is based unequivocally on cell theory with its emphasis on physiology as the science of life that seeks to illuminate the mechanisms of living things. This changes the oft-quoted conjecture of Dobzhansky (1973) that ‘nothing in biology makes sense except in the light of evolution’ into ‘nothing in evolutionary biology makes sense except in the light of cell theory and its basis in physiology’.

5.2 Recapitulating the background to a renewal of evolution theory

5.2.1 Setting the scene (Chapter 2)

Chapter 2 on setting the scene begins with the case for using an ontology, a particular conceptual framework employed in information technology, to explore how evolution theory can be formulated for practical application across the entire One Health. In short, an ontology is an ordered structure of interrelated and purposefully defined concepts that underpins software function. Then follows some thoughts about factors that shape the operating environment for One Health. The list includes international affairs and economics, ethics and the practice of science, the universal access to knowledge and the translation and extension of knowledge and skills. Connections to contemporary methodologies for risk analysis and hazard characterisation are then outlined and highlighted as indispensable for applying evolutionary biology within One Health and addressing its challenges.

An ontology for evolution theory can bring about the 'paradigm shift in risk assessment' recommended for tracking the drivers of disease emergence, spread and persistence and providing knowledge for the design and execution of countermeasures (FAO, 2013a). Knowledge sharing between One Health and evolutionary biology can claim to have mutual benefits. Agriculture and resources management as components of One Health have a history of contributing crucial knowledge to evolutionary biology. Darwin used observations from the selective breeding of plants and animals to substantiate natural selection. Natural selection within the proposed ontology refers to the consequences of interactions between the nature or essential properties (Nature A – Essence) of life forms and the nature or essential properties of the environment. Darwin talked of artificial and natural selection but both depend entirely on the nature of the environment.

Perspectives from international affairs and economics overlap through the notion of global public goods, which are 'goods with benefits that extend to all people and generations' (Kaul and Mendoza, 2003). The tripartite collaboration between the FAO, WHO and WOAH (2017) epitomises the global public good and has matured into the One Health Action Plan (2022-2026) which recognises the importance of solidarity and that the health of people, animals and the environment is intertwined. This Action Plan states that 'the combined knowledge, insights and technical capacities in food, agriculture, and human and animal health can generate strong synergies, which will yield more robust, effective and cost-efficient solutions to the complex problems facing the world today'. The scholarly values of knowledge or learning societies and open science (OECD, 1996; World Bank, 2002; UNESCO, 2005 and 2012; Stiglitz and Greenwald, 2014; WHO, 2020a; UNESCO, 2021) can realise this 'combined knowledge' as a global public good and the proposed ontology is a potential contributor to its practical application.

Perspectives from ethics and the practice of science also overlap in the settings for One Health. Norms of behaviour that guide the sound practice of science are suitably grounded in One Health by the Belmont principles of beneficence (doing good), non-maleficence (not doing harm), autonomy

(respect for persons and their agency) and justice (the equitable distribution of beneficence and non-maleficence)(Beauchamp and Childress, 1994). These principles rule out the malign misinterpretations of theory of evolution by natural selection that allowed for eugenics and social Darwinism. Another ethical concern is the obligation of actors within One Health to maintain and develop skills. Beneficence and non-maleficence require skills that are supported by reliable and continually updated knowledge (Berglund, 2007). Reliable knowledge comes from disinterested or objective reflection and analysis. Disinterestedness (D, putting truth and duty above self) joins three other matters to form the acronym CUDOS in the Mertonian norms for scientific integrity. These are communalism (C, collegiality and the common ownership of science and its products), universalism (U, free and open access to scientific pursuits and products) and organised scepticism (OS, exposure to critical scrutiny and possible refutation).

Matters identified in the practice of science apply throughout the renewal of theory of evolution by natural selection and point to the proposed ontology as an important opportunity for addressing current and future challenges in One Health. A guiding premise is that science is served by laws and theories as separate but mutually supporting concepts. A law in science is a ‘descriptive generalization about some aspect of the natural world’ (National Academy of Sciences, 1998) and is exemplified by the laws of thermodynamics and motion in the physical sciences. Theories are ‘comprehensive explanations of aspects of nature that are supported by vast bodies of evidence such that they can be used to make predictions about natural events or phenomena that have not yet been observed (National Academy of Sciences, 2009). Theories maintain and enhance their usefulness by being revised and expanded in detail in the light of new knowledge (Mayer and Gamble, 2024). This is amply demonstrated by atomic theory which forms the basis of chemistry and which over time has incorporated advances made by John Dalton, Michael Faraday, J.J. Thomson, Robert Millikan, Ernest Rutherford, Henry Moseley, Niels Bohr, Louis de Broglie, Erwin Schrodinger, Dmitri Mendeleev and more (see University of Pennsylvania, https://www.sas.upenn.edu/~dbalmer/eportfolio/nature_timeline.pdf).

Evolution theory (the theory of evolution by natural selection) teams with cell theory and germ theory as one of only three defensible scientific theories that operate in biology[97]. Other proposed theories may operate as subsets of these three broad foundational theories. The history of germ theory outlined in section 2.4.2b demonstrates how semantic and terminological confusion, ambiguities and vagueness can impede the progressive enhancement and practical utility of theories. The same issue has also affected evolution theory and these problems and their impacts have been examined according to the passage of time. Confusion around the meaning of theory in science and theory in the sense of a conjecture or speculation came to to light as a critical defect; that demands remedy. In this regard, the definition of theory from the National Academy of Sciences (2008) dubbed Theory A (Science) can be seen as an historical turning point that justifies a renewal of evolution theory. Implications flowing from the crucial sense of Theory A (Science) were elaborated according to the need for universal access to knowledge and the value of history in

[97] See https://en.wikipedia.org/wiki/Category:Biology_theories.

advancing evolutionary biology. An ontology constitutes an ingenious and self-evident method for renewing evolution theory in an intelligible, accessible and practically useful form.

Universally intelligible and accessible exchange of information and knowledge drives One Health and requires systems of communication unimpeded by language barriers. International bodies like the WHO, the FAO, the WOAH, the OECD and the World Bank address this matter by having multiple official languages that include English, French, Spanish, Arabic, Chinese and Russian. FAO has the Agricultural Information Management System (AIMS, https://aims.fao.org)and AGROVOC, a multilingual controlled vocabulary (https://www.fao.org/agrovoc/home), that seeks to improve access to knowledge and assist global food production. Factors affecting language barriers and information management include the primary vehicular or bridge language for science and hazards to clarity such as semantic and terminological confusion and misconceived concept hierarchies. Accidental or deliberate misinformation and disinformation, are additional hazards that disrupted responses to the COVID-19 pandemic (West and Bergstrom, 2021). All these matters have remedies including published protocols for risk analysis typified by FAO's classic *Manual on the Preparation of National Animal Disease Emergency Preparedness Plans* (Geering et al., 1999) and professional practices. The ontology for evolution theory can mediate innovation across the whole of biology by fostering the synergism between the know-how of technology and the know-why of academic science (Ritchie-Calder, 2007) and can facilitate reciprocal exchange of knowledge between general biology and the specific field of evolutionary biology.

Many different languages have dominated science at various times and in various places. English, however, has arisen as the major vehicular, bridge or common language for the sharing of science. English here refers to World English (McArthur, 1999), which is a global resource not a linguistic hegemony or sectional vainglory and one that continually upgrades its vocabulary with words imported from other languages. Over time, World English has embraced working concepts such as cell, metabolism, atom and molecule and World English can claim a unique foundational role in computer technology. Non-Latin and non-phonetic characters required the advent of UNICODE software in 1991 for their representation on personal computers. Any vehicular language for science, World English or otherwise, requires continual refinement to rectify defects and deficiencies. World English succeeded from German, French, Latin and Greek as the vehicular, bridge or common language of science that can disseminate working concepts such as ‘cell’, ‘metabolism’, ‘atom’ and ‘molecule’, tools such as the Système International (d'Unités) and global naming systems used in disciplines such as biology and geology, and science as the body of knowledge that belongs to humanity (Hohenberg, 2010). This succession from earlier dominant vehicular languages to English has been chronicled by (Gordin, 2015). Globalisation, the process by which social institutions are adopted on a global scale, has been a driver of change and has been assisted by the appearance of academic databases and search engines on the Internet. These processes of change continue and the notion of multiple vehicular languages for science has come into play.

The concept of English as the single vehicular language for science is becoming obsolete. Less than 15% of the world's population speak English (https://www.ethnologue.com/). Accordingly, recognising and alleviating the difficulties faced by nonnative speakers of English is a necessary step towards an inclusive global community of scientists and universal accessibility to scientific knowledge and its benefits. Hence, the FAO initiatives of AIMS and AGROVOC and the proposed ontology that can make evolution theory universally accessible and actionable. Linguistic diversity in science is being pursued as part of the open science initiative and has been given impetus by the *Helsinki Initiative on Multilingualism in Scholarly Communication* (2019) with support from UNESCO (2022) and the Council of the European Union (2022). The key issue is that any vehicular language must be purged of vernacular hindrances to enable effective communication between people with different native languages.

Attention to the nature of a vehicular language as a tool for effective communication is essential for untangling the semantic and terminological confusion that has afflicting the literature around evolution as recounted by Keller and Lloyd (1992) and Laland and Brown (2002). Laland and Brown (2002) state that theory of evolution by natural selection applied to human behaviour and society has become a 'minefield of terms and concepts'. Keller and Lloyd (1992) analyse thirty three words in the history of evolution that have been 'plagued in their usage by multiple concurrent and historically varying meanings'. The words theory, nature and natural are added at the top of this list. They have meanings that are paramount in the renewal of evolution theory and remedying its past encumbrances.

The next steps are recapitulated according to matters in the history of evolution theory described in Chapter 3 and an update on current practice and knowledge in biology described in Chapter 4. The reliability of the proposed ontology for theory of evolution by natural selection in meeting the present-day needs of One Health derives from its alignment with present-day biological knowledge and its refinement as knowledge advances.

5*.2.2 A view of evolution theory according to its history (Chapter 3)*

The approach to renewing evolution theory was elucidated by analysing where and how salient polysemous and troublesome words were used in various documents that came after publication of *Origin of Species* and whether this usage indicated an appreciation of the nature of laws, theories and hypotheses in the practice of science. The words theory and nature (noun) plus natural (adjective) were the primary concern in this case study and were complemented with 34 other words that have affected past expositions of evolution theory. This process of textual scanning also informed some of the definitions of concepts necessary for rigour within the proposed ontology.

Three relevant senses of the word 'theory' were identified in the Encarta World English Dictionary and were cross-referenced to the Webster's Dictionary of 1828 and the Oxford English Dictionary (Simpson and Weiner, 1989). Theory A (Science) refers to the sense of a 'scientific principle to explain phenomena' and is consistent with the word as it applies within science (National Academy

of Sciences, 1998 and 1999; National Research Council, 2008). This sense dates to at least 1828 and possibly to 1638 (Simpson and Weiner, 1989) and is not present in the keyword fields of Roget's Thesaurus and the Macquarie Thesaurus. The words 'doctrine' and 'dogma' are decidedly not synonyms for Theory A (Science). Theory B (Idea) merges the senses of 'speculation', 'idea formed by speculation' and 'hypothetical circumstances' and dates to at least 1828. Theory B (Idea) is present in the keyword fields of Roget's Thesaurus and the Macquarie Thesaurus. Theory C (Principles) refers to the sense of the 'rules and techniques applying to a particular subject' as in music theory. Theory C (Principles) is not present in the keyword fields of Roget's Thesaurus and the Macquarie Thesaurus.

Three relevant senses of the words 'nature' (noun) plus 'natural' (adjective) were identified in the Encarta World English Dictionary and were cross-referenced to the Webster's Dictionary of 1828 and the Oxford English Dictionary (Simpson and Weiner, 1989). The Encarta Dictionary lists eleven senses of the word nature which were amalgamated into three classes for the process of textual scanning. First is Nature A (Essence) which has the senses of the intrinsic character of a person or thing or the real appearance or aspect of a person or thing and this usage dates to at least 1828. Nature A (Essence) is present in the keyword fields of the Macquarie Thesaurus. Nature B (Forces) has the sense of the 'forces controlling the living world'. This usage dates to at least 1828 and is absent from the keyword fields of the Macquarie Thesaurus. Nature C (Physical World) has the sense of the physical world including all natural phenomena and living things. This usage dates to at least 1828 and is present in the keyword fields of the Macquarie Thesaurus and Roget's Thesaurus.

Nature B (Forces) functions in Darwin's view of natural selection within *Origin of Species* and frames the scientific knowledge available at the time. Page 63 of *Origin of Species* reflects Nature B (Forces) when it states that: 'So again it is difficult to avoid personifying the word Nature; but I mean by Nature, only the aggregate action and product of many natural laws, and by laws the sequence of events as ascertained by us'. Forces are implied within the phrase 'aggregate action and product of many natural laws' and this leads to wider notions of causality and causation. In consequence, forces as agents of change can be aligned with present day scientific knowledge where evolution is a phenomenon and natural selection provides its causal processes. Nature as Nature A (Essence) explains the causal processes or 'forces' of evolution and supersedes Nature B (Forces) in structuring the ordered sequence of concepts that make up proposed ontology and shape the definition of natural selection. The definition of natural selection designed for the proposed ontology centres on the consequences of interactions between the nature or essential properties of life forms and the nature or essential properties of the environment and is shown below.

> *Natural selection is the process that occurs when life forms (organisms and sub-cellular infectious agents such as viruses and prions) interact with their environment according to their own nature, or intrinsic characteristics and properties, and the nature of their environment and its biotic and abiotic elements. Natural selection results in 'descent with modification' or generational change whereby forms of organisms or other life forms in a population that are better adapted to an environment increase in frequency relative to less*

> *well adapted forms. The process of natural selection works through a means likened to a passive filter where selection and elimination of phenotypes according to their viability is accompanied by selection and elimination of the associated genotypes.*

A sample of books from the field of biology that demonstrate different perspectives on tevolution theory were used in a case study that explored the incidence and usage of two sets of words. The first set of words for the case study comprised theory, nature and natural and were accompanied by doctrine, hypothesis, dogma and thesis and the suffix -ism which overlap with some senses of the word theory and are completely incompatible with Theory A (Science). The search for nature and natural led to the use of Nature A (Essence) in the definition of natural selection designed for the proposed ontology and described above. This sense of nature centres on the consequences of interactions between the nature or essential properties of life forms and the nature or essential properties of the environment.

The search for theory in the case study demonstrates progress towards a proper understanding and correct use of the word. Theory A (Science) was absent from the works of Spencer (1887 and 1889) Fisher (1930) Haldane (1932) and Huxley (1942). This unexpected finding renders these highly influential works defective and inapplicable to present day needs. Mayr (2001) reiterates an opinion of Gould (1981) that evolution was a fact rather than a theory in the sense of Theory B (Idea). The proposed ontology will present evolution or descent with modification as a phenomenon or observable fact that can be explained coherently in terms of Theory A (Science). Theory A (Science) provides landmarks for knowledge and facts are entailed in knowledge. Thankfully, progress has been made and Theory A (Science) has clear-cut use in contemporary textbooks on evolutionary biology (Hall et al., 2014; Zimmer and Emlen, 2016; Futuyma and Kirkpatrick, 2017). This final observation establishes an ontology for evolution theory based on Theory A (Science) as a rational and timely development that can remedy past misconceptions and impediments to understanding.

The second set of words explored in the case study comprised several groupings. Fit, fitness, adapt and adaptation grouped together because they have been obscured in meaning and come under discussion at various times according to ‘adaptation-ism’ and ‘selection-ism’ (see Lewontin, 1957; Brandon, 1978; Orzack and Sober, 2001; Orzack and Forber, 2017; Segerstrale, 2000). Fitness and adaptation require precising definitions that can empower the proposed ontology for theory of evolution by natural selection and remove the encumbrances of ‘adaptationism’ and ‘selectionism’. The precising definition determined for fitness is ‘*the success of an organism or a sub-cellular infectious agent, such as a virus or prion, at being viable and surviving and then contributing descendants to future generations’*. The precising definition determined for adaptation is *any peculiarity, property or feature of the structure, physiology or behaviour of an organism or biological entity, such as a virus or prion, that enables it to be viable and to survive and reproduce in a particular environment.* Adaptations are depicted as capabilities that operate in the processes of the causation unit (compound of component causes) that applies to the ontology for theory of evolution by natural selection.

Other groupings in the second set of words for the case study begin with environment, viable, viability and metabolism. These words and their underlying concepts were unavailable to Darwin and could have replaced his necessity to use of figurative and allusive language in *Origin of Species*. Darwin's phrase, the 'conditions of life', encompassed the current ecological meaning of environment and the workings of life forms. Viability is the crux of definitions for fitness and is depicted as follows: *Viability for organisms is the capability for life, being alive and living and for biological entities such as viruses and prions is the capability for existing and executing life cycles based on propagation within organisms and transmission among organisms*. Darwin's allusions to the 'struggle for life' and 'struggle for existence' could have been embellished by reference to metabolism as *the integrated network of biochemical reactions that support viability in living organisms and biological entities such as viruses and prions.*

Race was searched for in the case study because of its harmful interpretations within eugenics and social Darwinism. Its meaning can conveyed by the word population as it applies in epidemiology and ecology: *A population is any complete group with at least one characteristic in common or an aggregate of things, creatures, cases and so on*. Reproduction and replication explored because they must be differentiated in order to connect the ontology for theory of evolution by natural selection with the central biological concept of organisation. Replication refers to the *duplication of informational macromolecules by life forms and reproduction refers to the processes whereby life forms give rise to new individuals of their kind*. Life forms include viruses and prions which must be catered for in the ontology. Behaviour, performance, capability and capacity were searched for because they refer to the observed entities or facts that drive knowledge about the natural world. 'Observations are the conduit through which the "tribunal of experience" delivers its verdicts on hypotheses and theories' (Boyd and Bogen, 2021).

The pursuit of precising definitions for components of the ontology for evolution theory continued with another scan of *Origin of Species* based on the premise that it contained the enduring elements of evolution expressed in the vocabulary available to Darwin. Section 3.3 investigated the problematical phrase 'survival of the fittest' and this led to further investigations and reflections that produced precising definitions for fitness, adaptation and selection. Examination for the words inheritance (which Darwin qualified with the phrase 'as implied by reproduction'), variation and selection showed that these were the firm pillars for evolution in *Origin of Species* and remain so today. These pillars have been illuminated not displaced by advances in knowledge about the processes and mechanisms that drive them. Included here are advances in genetics that began with the work of Mendel (Sturtevant, 2001). Sometimes, however, terms around these process and mechanisms have been 'plagued in their usage by multiple concurrent and historically varying meanings (Keller and Lloyd, 1992). The ontology for evolution theory builds around inheritance as the transmission and reception of genetic information from generation to generation via the processes of reproduction and heritability as the capacity for being transmitted from one generation to the next.

Issues around the term species and their implications for the proposed ontology were also explored in Chapter 3. Zachos (2016) provided a list of 32 annotated species concepts all of which suited particular purposes in different branches of biology. Many concepts in the list are similar. Some may be synonyms and all can be reckoned as suiting a particular purpose within the broad scope of biology. Mayr (1996) offered the biological species concept as a way of catering for all definitions. Seven textbooks from the twenty first century that pitched towards the biological species concept were consulted as a means of assembling a precising definition of a species suited to the ontology for theory of evolution by natural selection (Freeman and Herron, 2001; Hickman et al., 2001; Mayr, 2001; Campbell and Reece, 2002; Ridley, 2004; Zimmer and Emlen, 2016; Futuyma and Kirkpatrick, 2017). The result shown below extends to biological entities such as viruses and prions[98], which clearly exhibit Darwin's 'descent with modification'.

> *Species are discrete populations of organisms (some of which are holobionts, see section 4.2.3) or sub-cellular and non-organismal life forms such as viruses, viroids and prions (so-called semibionts, see sections 4.3.5 and 4.3.6) which share structural and functional attributes. Some of these attributes implement and control the propagation and exchanges (vertical, horizontal or both) of genetic material[99] as whole genomes through successive generations. These attributes create barriers to reproduction and opportunities for reproduction that demarcate one discrete population from another. Species contain subsets or subpopulations[100] with diverse capabilities that provide for variation.*

In short, species are discrete populations of life forms possessing communal properties for reproduction. The phrase 'propagation of genetic material[101] as whole genomes through successive generations' in the definitions can forestall possible confusion arising from mobile genetic elements which are sequences of genetic material that can change places within a genome, and can be exchanged between genomes (modified from Foxman, 2012). Mobile genetic elements include 'plasmids, prophages, pathogenicity islands, restriction and modification systems, transposons, and insertion sequences, among others, that share the ability to be transmitted vertically with cell division or through horizontal transfer' (Vale et al., 2022). The idea of species as reproductively circumscribed populations of life forms allows for the phenomenon of genome mixing that occurs in viruses and drives the emergence of new disease causing variants.

Genome mixing occurs when informational macromolecules (DNA or RNA) from two or more individual genomes split and then recombine to form new genes or allele combinations. Reassortment is a version of recombination occurs in negative-sense single-stranded RNA viruses

[98] The writings that made for the modern synthesis (Fisher, 1930; Haldane, 1932; Huxley, 1942) contain a single passing reference to a virus being a possible cause of variation in *Drosophila* spp. of fruit-fly (Huxley, 1942).

[99] As explained in section 4.2.8, the genetic material of prions is protein not DNA or RNA.

[100] The terms suprapopulation, infrapopulation and component populations have a particular use within the discipline of parasitology (Bush et al., 1997; Margolis et al., 1982) and are not apt for present purposes. A suprapopulation is all individuals of a species of parasite in all stages of development within all hosts in an ecosystem. An infrapopulation is all individuals of a species of parasite occurring in an individual host.

[101] As explained in section 4.2.8, the genetic material of prions is protein not DNA or RNA.

with segmented genomes and refers to recombination between segments. Genome mixing requires hosts that can be infected simultaneous with two or more variants of the same viral species. These have been named mixing vessel hosts (Scholtissek, 1987; Yasuda, 1991; Abdelwhab and Mettenleiter, 2023). Abdelwhab and Mettenleiter (2023) list humans, pigs, minks, ferrets, seals, dogs, cats, and birds, particularly turkeys, chickens, quails, and ducks as probable mixing vessel hosts for avian influenza viruses that have a high zoonotic potential.

5.2.3 Pathways to the renewal of evolution theory according to contemporary biology and the demands of One Health (Chapter 4)

The third and last part of this 'one long argument' or process to renew evolution theory for present-day use in One Health began in Chapter 4 with a commentary on opportunities from information technology (IT) for packaging biological knowledge and optimising its practical and productive application. Reliable and effective performance in information technology (IT) requires a clear-cut and unambiguous comprehension of ideas, entities, factors and variables and their relationships that can be obtained by means of precising definitions (see section 1.1.4) and the use of concept hierarchies. The same requirement applies to the present renewal of the theory of evolution by natural selection and can met by approaches used in information technology (IT), artificial intelligence and knowledge engineering. Ontologies, or 'representations of knowledge as a set of concepts and relationships that exist among those concepts' (Neapolitan and Jiang, 2018), provide the methodology and their utility can generalise across all forms of rational discourse. An ontology can rectify the adverse impacts of linguistics, diction and argumentative discourse on past expositions of theory of evolution by natural selection (see Chapter 3). Ontologies are given sense by a clear and diagrammatic view of their determinants and components.

Diagrams were explored in Chapter 4 as a means for enhancing cogitation and facilitating communication were instrumental in the renewal of evolution theory for application in One Health. Ontologies employed in information technology and artificial intelligence qualify as diagrams as does the ontology proposed for evolution theory, which will be instructed by the generic concept hierarchy proposed in section 2.1 and explained in Table 2 and Figure 1. Groundwork for organising and assembling this ontology comes from a series of diagrams that illuminate the elements of evolution theory. The series starts with a triangle that depicts the scope of biology and unifies and coordinates germ theory, cell theory and evolution theory for practice in One Health (Figure 2, section 2.2). The series continues with Figure 4 (section 4.1.1) that outlines the archetype of the fire triangle, the example of the epidemiological triangle and attempts at triangles for germ theory and evolution theory. The epidemiological triangle and the triangles for germ theory and evolution theory highlight the commonality of interactions between life forms and the environment and the role of agency in producing either disease, infectious disease or evolution. The four triangles in Figure 4 are shown in detailed form in Figures 5, 6, 7 and 8 in section 4.4.

Darwin used the phrase 'the laws acting around us' to explain the component causes that bring about evolution in life forms. The word 'laws' is supplemented by the word 'factors' to highlight the

present day meaning of laws in science as concise statements that describe consistent, observable relationship in nature. These ‘laws’ or ‘factors’ are explained according to current biological knowledge and with an emphasis on physiology. Renewal of the substance of evolution theory was expedited by Figure 9 which sets out the structure of the proposed ontology in line with a concept hierarchy and points to the precising definitions for its component parts. These enlighten ‘the laws [factors] acting’ in life forms and also in the environment. Figure 9 frames some further reflections and is a resource for finalising the ontology for evolution theory in Chapter 6.

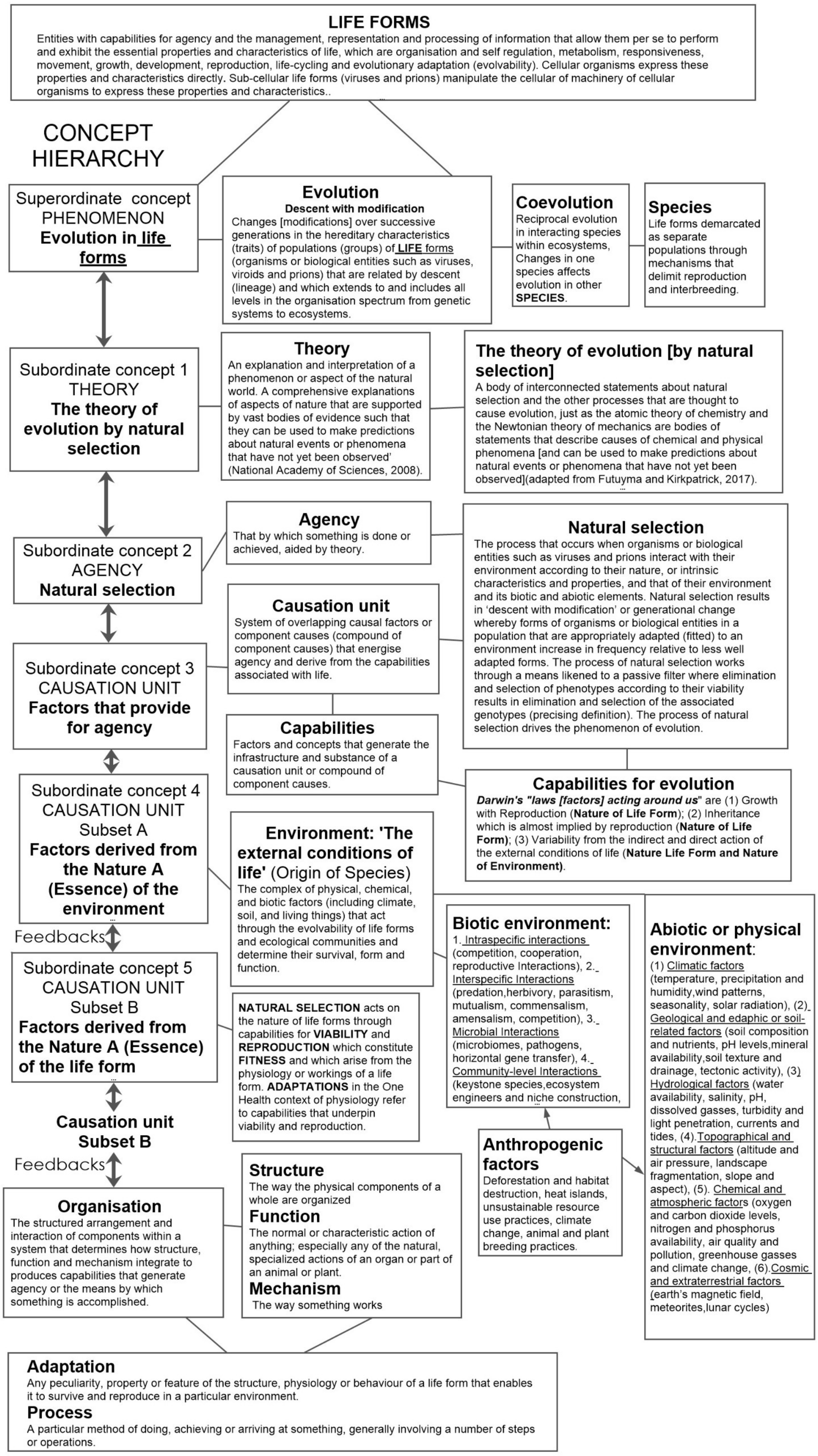
LIFE FORMS
Entities with capabilities for agency and the management, representation and processing of information that allow them per se to perform and exhibit the essential properties and characteristics of life, which are organisation and self regulation, metabolism, responsiveness, movement, growth, development, reproduction, life-cycling and evolutionary adaptation (evolvability). Cellular organisms express these properties and characteristics directly. Sub-cellular life forms (viruses and prions) manipulate the cellular of machinery of cellular organisms to express these properties and characteristics..
CONCEPT HIERARCHY
Superordinate concept PHENOMENON Evolution in life forms
Evolution
Descent with modification
Changes [modifications] over successive generations in the hereditary characteristics (traits) of populations (groups) of LIFE forms (organisms or biological entities such as viruses, viroids and prions) that are related by descent (lineage) and which extends to and includes all levels in the organisation spectrum from genetic systems to ecosystems.
Coevolution
Reciprocal evolution in interacting species within ecosystems, Changes in one species affects evolution in other SPECIES.
Species
Life forms demarcated as separate populations through mechanisms that delimit reproduction and interbreeding.
Subordinate concept 1 THEORY The theory of evolution by natural selection
Theory
An explanation and interpretation of a phenomenon or aspect of the natural world. A comprehensive explanations of aspects of nature that are supported by vast bodies of evidence such that they can be used to make predictions about natural events or phenomena that have not yet been observed' (National Academy of Sciences, 2008).
The theory of evolution [by natural selection]
A body of interconnected statements about natural selection and the other processes that are thought to cause evolution, just as the atomic theory of chemistry and the Newtonian theory of mechanics are bodies of statements that describe causes of chemical and physical phenomena [and can be used to make predictions about natural events or phenomena that have not yet been observed](adapted from Futuyma and Kirkpatrick, 2017).
Subordinate concept 2 AGENCY Natural selection
Agency
That by which something is done or achieved, aided by theory.
Natural selection
The process that occurs when organisms or biological entities such as viruses and prions interact with their environment according to their nature, or intrinsic characteristics and properties, and that of their environment and its biotic and abiotic elements. Natural selection results in 'descent with modification' or generational change whereby forms of organisms or biological entities in a population that are appropriately adapted (fitted) to an environment increase in frequency relative to less well adapted forms. The process of natural selection works through a means likened to a passive filter where elimination and selection of phenotypes according to their viability results in elimination and selection of the associated genotypes (precising definition). The process of natural selection drives the phenomenon of evolution.
Subordinate concept 3 CAUSATION UNIT Factors that provide for agency
Causation unit
System of overlapping causal factors or component causes (compound of component causes) that energise agency and derive from the capabilities associated with life.
Capabilities
Factors and concepts that generate the infrastructure and substance of a causation unit or compound of component causes.
Capabilities for evolution
Darwin's "laws [factors] acting around us" are (1) Growth with Reproduction (Nature of Life Form); (2) Inheritance which is almost implied by reproduction (Nature of Life Form); (3) Variability from the indirect and direct action of the external conditions of life (Nature Life Form and Nature of Environment).
Subordinate concept 4 CAUSATION UNIT Subset A Factors derived from the Nature A (Essence) of the environment
Environment: 'The external conditions of life' (Origin of Species)
The complex of physical, chemical, and biotic factors (including climate, soil, and living things) that act through the evolvability of life forms and ecological communities and determine their survival, form and function.
Feedbacks
Subordinate concept 5 CAUSATION UNIT Subset B Factors derived from the Nature A (Essence) of the life form
NATURAL SELECTION acts on the nature of life forms through capabilities for VIABILITY and REPRODUCTION which constitute FITNESS and which arise from the physiology or workings of a life form. ADAPTATIONS in the One Health context of physiology refer to capabilities that underpin viability and reproduction.
Biotic environment:
1. Intraspecific interactions (competition, cooperation, reproductive Interactions), 2. Interspecific Interactions (predation,herbivory, parasitism, mutualism, commensalism, amensalism, competition), 3. Microbial Interactions (microbiomes, pathogens, horizontal gene transfer), 4. Community-level Interactions (keystone species,ecosystem engineers and niche construction,
Abiotic or physical environment:
(1) Climatic factors (temperature, precipitation and humidity,wind patterns, seasonality, solar radiation), (2) Geological and edaphic or soil-related factors (soil composition and nutrients, pH levels,mineral availability,soil texture and drainage, tectonic activity), (3) Hydrological factors (water availability, salinity, pH, dissolved gasses, turbidity and light penetration, currents and tides, (4).Topographical and structural factors (altitude and air pressure, landscape fragmentation, slope and aspect), (5). Chemical and atmospheric factors (oxygen and carbon dioxide levels, nitrogen and phosphorus availability, air quality and pollution, greenhouse gasses and climate change, (6).Cosmic and extraterrestrial factors (earth's magnetic field, meteorites,lunar cycles)
Causation unit Subset B
Feedbacks
Anthropogenic factors
Deforestation and habitat destruction, heat islands, unsustainable resource use practices, climate change, animal and plant breeding practices.
Organisation
The structured arrangement and interaction of components within a system that determines how structure, function and mechanism integrate to produces capabilities that generate agency or the means by which something is accomplished.
Structure
The way the physical components of a whole are organized
Function
The normal or characteristic action of anything; especially any of the natural, specialized actions of an organ or part of an animal or plant.
Mechanism
The way something works
Adaptation
Any peculiarity, property or feature of the structure, physiology or behaviour of a life form that enables it to survive and reproduce in a particular environment.
Process
A particular method of doing, achieving or arriving at something, generally involving a number of steps or operations.

Figure 9: Diagram setting out the proposed ontology for evolution theory in detailed form and according to concept hierarchy where the phenomenon of evolution is the superordinate concept and where subordinate concepts concern explanations, agency and causation.

One determinant of the proposed ontology for evolution theory according to Theory A (Science) is the premise that this theory, cell theory and the germ theory of disease form a cohesive and interdependent trio of broad foundational theories that supports the whole of biology as shown in Figure 2 (Chapter 2). The whole of biology includes One Health and the practical wisdom, ‘phronesis’, that drives its application (Abassi, 2011). Atomic theory does the same thing as this trio of theories and integrates the whole of chemistry. The trio of evolution, cell and germ theories converts the aphorism of Dobzhansky (1973) that ‘nothing in biology makes sense except in the light of evolution’ into ‘nothing make sense in evolutionary biology except in the light of germ theory and cell theory’. Cell theory is a necessary starting point for explaining the processes of evolution or what Darwin termed ‘descent with modification’. Evolution theory embellishes the perspectives, insights and foresight provided by cell theory and germ theory.

Another determinant of the proposed ontology for evolution theory explored in Chapter 4 is that its usefulness, soundness and safety is contingent upon the precision and accuracy of definitions and an unequivocal grasp of the processes that guide science and critical thinking. Definitions seek to ascertain and encapsulate the characteristics and nature of a thing, in line with Nature A (Essence), and so identify and explain what a thing is. A definition is an exact statement or description of the nature, scope and meaning of something (see Glossary). Precising definitions have been constructed for all matters in the proposed ontology for evolution and are open to modification in the light of new knowledge. Precising definitions have the purpose for reducing the vagueness of a term and are mandated for the ontologies used in computer technology. Evolution, Darwin’s descent with modification, applies to life forms and reliability of the ontology for evolution theory turns on the precising definition for these entities as shown at the top of Figure 9. Physiology, is the branch of biology that aims to understand the mechanisms of living things.

Processes that guide science and critical thinking were pondered in section 4.1.2b. Explanations, summed up as statements or accounts that make something clear, mesh with critical thinking or the means for making reasonable decisions about what to believe and what to do (Damer, 2005). Theories in the sense of Theory A (Science) make phenomena clear for the knowledge annd reasoning that makes for sound action. Critical thinking unifies the methods used across science and the practical wisdom (phronesis), causal reasoning and hypothetico-deductive processes that govern One Health. As a result, the issue of teleology becomes a present day irrelevancy and the historical tensions between so-called functional biology with its emphasis on proximate causation and evolutionary biology with an emphasis on ultimate causation (Mayr, 1961) becomes a matter for history (see section 1.1.3). Proximate causes and ultimate causes are linked and identify as the component causes (Rothman and Greenland, 2005) that are covered in the medical concept of aetiology. Component causes make up the causation unit that provide for agency in the ontology for evolution theory. Component causes are covered by subordinate concepts 3, 4 and 5 in Figure 9.

A final word of paramount importance is that Figure 9 displays a precising definition for species, which can expedite an understanding of the mutation rates in viruses that drive their evolution and lead to the continuing epidemic and pandemic viral diseases that confront One Health and provide abundant cause for the renewal of evolution theory. Species are depicted as discrete populations of life forms that possess communal properties for reproduction. Mutation rates in viruses vary according to the nature of informational macromolecules and mutation rates in single-stranded RNA viruses such as the influenza, MERS, SARS CoV-1 and SARS CoV-2 viruses can be prodigious. The consequence is continual emergence of new forms of epidemic and pandemic diseases. Two sources of mutation are in play. One is the absence of proof-reading mechanisms in single-stranded RNA viruses that govern genome replication. The other is genome mixing which requires hosts that can be infected simultaneous with two or more variants of the same viral species and interactions between multiple host species. Some hosts may be non-permissive to some of these variants but can become permissive to new variants when mixing vessels hosts are present. Mixing vessel hosts are permissive to concurrent infections with multiple variants of a viral species and allow for the genome mixing that generates new viral subpopulations with new capabilities including extended host ranges, virulence, modes of transmission and persistence in the environment.

Chapter 6. The Ontology for Evolution Theory and Its Potential for Illuminating Infectious Disease Emergence

‘It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the external conditions of life, and from use and disuse; a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms’.

From last paragraph in all editions of Darwin’s *Origin of Species.*

‘As this whole volume is one long argument, it may be convenient to the reader to have the leading facts and inferences briefly recapitulated’.

From Chapter XIV or XV, Recapitulation and Conclusion, in all editions of Darwin’s *Origin of Species*.

This reformulation of Darwin’s ‘one long argument’ culminates in a worked example of an ontology directed at the comprehensive renewal of theory of evolution by natural selection (evolution theory) for application in One Health and making this theory and evolutionary biology as accessible, comprehensible and actionable as cell theory and germ theory. The ontology is tailored to the objectives, needs, working culture and ethos of One Health as a global common good that operates for the health and well-being of people, animals and the environment. Ontologies of the sort in mind set foundations for information technology and artificial intelligence through structured and detailed representations of relevant concepts, entities and their relationships (Neapolitan and Jiang, 2018) and in doing so provide a model for generalised use. Ontologies provide an opportunity for the effective and efficient communication of knowledge that was unavailable before the consolidation of the information or computer age in the last part of the twentieth century (Coggan, 2020).

The ontology for evolution theory is founded on the premise that evolution theory, cell theory and germ theory act as harmonised and interdependent trio that can enlighten the practice of One Health. Cell theory acts as the super-ordinate theory within this trio because it frames the attributes, properties, elements, conceptions and characteristics that identify life, living entities and viability. Cell theory explains the order and organisation that allows for patterned transformations of matter, energy and information and in doing so provides the substance necessary for evolution theory and germ theory. The trio of evolution theory, cell theory and germ theory is pictured as a triangle, reminiscent of the epidemiology triangle, in Figure 10 below.

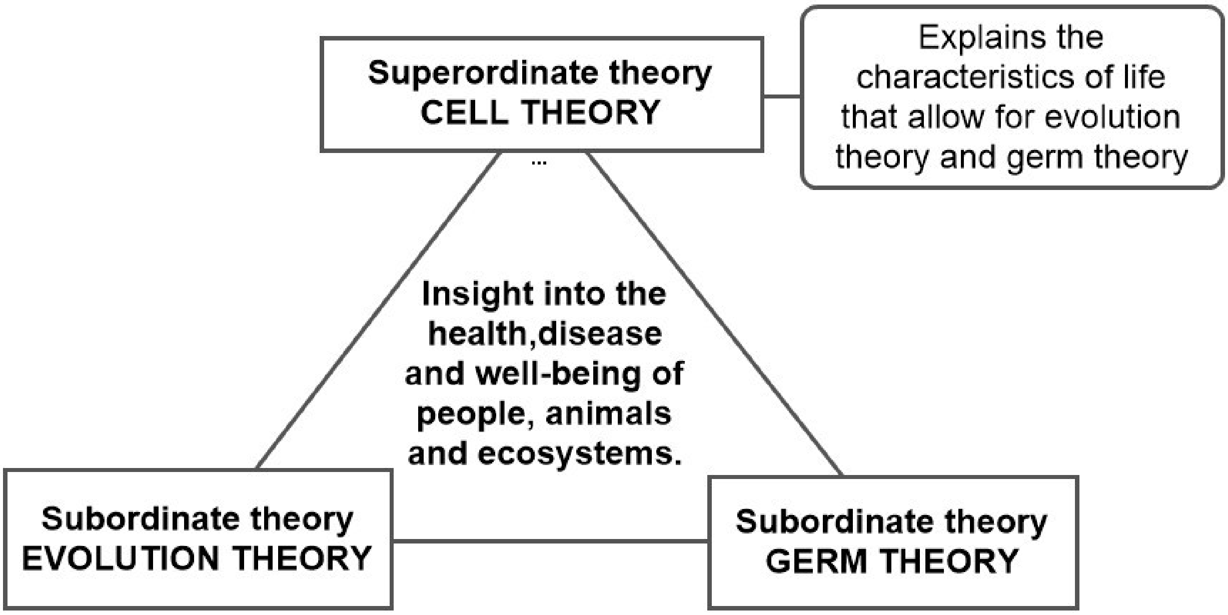

Figure 10: The interdependent trio of theories that inform biology and One Health depicted as a triangle reminiscent of the epidemiology triangle. Cell theory operates as as the superordinate theory and evolution theory and germ theory operate as subordinate theories.

Communication is crucial for global cohesion and cooperation and English as the current universal scientific language has problems that require attention and the ontology for evolution theory can help towards their remedy. Less than 15% of the world's population speak English (https://www.ethnologue.com/). An editorial by Drubin and Kellogg (2012) describes the impact of these language issues on publishing research results and discusses how researchers, manuscript reviewers, and journal editors can help towards equity in international scientific communication. Recognising and alleviating the difficulties faced by nonnative speakers of English is a necessary step towards universal and unfettered access to scientific knowledge and its benefits. An initiative in this regard comes from the AGROVOC and AIMS programs of the FAO, which are directed at mitigating language barriers, improving access to knowledge and assisting global food production and security. The ontology for evolution theory together with its set of precising definitions has similar objectives and form a resource for translation into any chosen language. They compose a comprehensive summation of evolution theory suited to the practical needs of One Health, without encumbrances and diversions resonating from the history of evolutionary biology and open to amendment in the light of new knowledge and critical feedback.

Background to the proposed ontology for evolution theory and the removal of past encumbrances comes from the turbulent history of evolutionary biology. Issues here concern ideological predilections that allowed for harmful and unconscionable Social Darwinism, forms of discourse that were argumentative and promotional rather than expository and the linguistic issues of ambiguity, such as confusion around words with more than one meaning (polysemy), and vagueness arising from figurative language. Precising definitions for key terms and concepts and a

comprehensive glossary aim at forestalling these linguistic problems and in a manner that prevents their transfer in translations to languages other than English.

The ontology for evolution theory was initiated by subjecting some prominent documents from the history of evolutionary biology to a defined process for textual analysis around a set of words with multiple meanings. The results demonstrate systemic failures to recognise or understand the distinction between laws, theories and hypotheses in science. Failures of this sort occurred in documents regarded as central to what was called neo-Darwinism or the Modern Synthesis (Fisher, 1930); Haldane, 1932; Huxley,1942) and amount to the quality control concept of a critical defect or a defect that renders a product unsafe or unusable (Evans and Lindsay, 1989). The words theory and nature were pivotal. In science, theory refers to a comprehensive explanation of aspects of nature that is supported by vast bodies of evidence such that that it can be used to make predictions about natural events or phenomena that have not yet been observed (National Academy of Sciences, 2008). This particular denotation is classed as Theory A (Science), scientific principle to explain phenomena, as opposed to Theory B (Idea), speculation or conjecture, or idea formed by speculation), or Theory C (Principles), a set of rules and techniques. Chemistry is founded squarely on atomic theory according to Theory A (Science).

As to the noun 'nature' and the adjective 'natural', Nature A (Essence) refers to the intrinsic character of a person or thing. Nature B (Forces) refers to the forces and processes collectively that control the phenomena of the physical world and Nature C (Physical World) refers to the physical world including all natural phenomena and living things. Nature B (Forces) operates silently in the practice of science and is implied in the prologue to *Origin of Species* which quotes a statement from the theologian, William Whewell (1794-1866), that 'divine power' acts through general laws. In consequence, the ontology proposed for evolution theory focusses on Nature A (Essence) and Nature C (Physical World).

Cell theory and germ theory operate silently within all disciplines supporting One Health and an ontology for evolution theory can provide the same silent operation for evolution theory. Accordingly, ontologies necessitate precising definitions, or definitions directed at reducing the vagueness of a term (Hurley, 2003), for their components and associated items (see section1.1.4). The set of precising definitions developed for the proposed ontology and their attention to ambiguities provides an exemplar for promoting intelligibility in all areas of knowledge. For example, the reliability of mathematical models depends upon clear descriptions of variables being modelled. Loose definitions in mathematical models are a source of harm and bear witness to the aphorism that 'all models are wrong, but some are useful' (George Box, 1919-2003)[102].

The ontology for renewing evolution theory for use in One Health was developed through a sequence of three steps and builds upon physiology as the science of life that seeks to illuminate the mechanisms of living things (https://www.physoc.org/explore-physiology/what-is-physiology/). A perspective on evolution theory framed around physiology rather than taxonomy, phylogeny and

[102]https://en.wikipedia.org/wiki/All_models_are_wrong

systematics can realise the benefits of evolution theory in One Health by a focus on vital functions such as metabolism, reproduction, respiration and thermoregulation and a view to the viability and adaptability of life forms. The ontology in mind can direct the processing of information and knowledge into insights that enable the prevention, diagnosis, control and management of the health and well-being of people, animals, and ecosystems (One Health High-Level and Expert Panel, 2022).

The first step towards an ontology for evolution theory was to construct a generic ontology applicable to the three broad foundational theories that inform biology. These are cell theory, germ theory and evolution theory. Entities labelled homeostasis theory, gene theory and endosymbiosis theory[103] do not meet the precising definition for theory and act as principles within biology's three foundational theories. Cell theory is paramount because it deals with mechanisms for the phenomenon of life and thus sets the scene for foundations for germ theory and evolution theory, which concern life. The precising definition of life states that life entails capabilities for agency and information management that control the transformations of energy and material necessary for vital functions and that these capabilities operate variously for cellular organisms and subcellular life forms such as viruses and prions. The generic ontology (Figure 1 in Section 2.1) has the structure of a concept hierarchy with phenomenon, or that which is observed or perceived to happen or exist, as the superordinate concept and theory, agency and causation unit as the successive. Theory refers to an explanation and interpretation of a phenomenon or aspect of the natural world. Agency refers to that by which something is done or achieved. Causation unit refers to the system of overlapping causal factors or component causes that energise agency. Matters like structure, function and mechanism and their unified action produced by organisation are covered here.

Superordinate concepts for cell theory, germ theory and natural selection theory are the phenomena of life, infectious disease and evolution or descent with modification. Cell theory proposes cells as the basic functional unit for all life forms, including viruses and prions which rely upon cells for their existence. Germ theory proposes that all infectious diseases are caused by germs or agents that possess the fundamental capabilities of life. Evolution theory proposes that evolution or descent with modification results from interactions between life forms and their nature or intrinsic characteristics and properties and the nature or intrinsic characteristics and properties of their environment. These interactions constitute the agency (natural selection) for evolution and its causation unit which involves reproduction, inheritance, variability and viability.

The second step in progress towards an ontology for evolution theory involves precedents set by the epidemiological triangle, which informs the management of disease and the fire triangle[104] , which informs firefighting and fire prevention. Triangles for germ theory and evolution theory were composed in outline form and then in more detailed form to guide the ontology for evolution theory and the set of precising definitions applying to its elements. An early observation was that a

[103]https://study.com/academy/lesson/how-biological-theories-develop.html

[104]The fire triangle itself is relevant to One Health because fires are environmental hazards or natural disasters that are being increased by climate change (Canadell et al, 2021).

renewed version of evolution theory can integrate with germ theory to meet the needs of One Health; for example, in understanding the factors that influence the emergence and re-emergence of infectious diseases. Renewed forms of evolution theory and germ theory can combine to assist with processes for prioritising pathogens for pandemic preparedness outlined by the WHO (see Ukuoka et al, 2024) and can bring about the 'paradigm shift in risk assessment' needed to track the drivers of disease emergence, spread and persistence and to design countermeasures (FAO, 2013a).

The third and last step finalises a pioneer version of the ontology that can guide the renewal of evolutionary biology for worldwide use in One Health. Figure 9 at the end of Chapter 5 shows this ontology in diagrammatic and detailed form to highlight the sequence of concepts in the concept hierarchy and to connect these concepts with the precising definitions for their components. Table 14 restates the contents of Figure 9 and marshals the terms and concepts with precising definitions that are detailed in Table 14. The contents of Tables 13 and 14, supported by that of Figure 9, serve as a comprehensive resource for translating the proposed ontology from English to other languages and making evolution theory as unencumbered and globally accessible as cell theory and germ theory. The ontology for evolution theory is open to the organised scepticism that empowers science (Merton, 1942) and is amenable to modification according to emerging knowledge.

Table 13: The structure and components in an ontology for evolution theory for world wide use in One Health. Terms and concepts identified by asterisks possess precising definitions as listed in Table 14.

STRUCTURE OF ONTOLOGY according to concept hierarchy	Components within successive levels of the concept hierarchy for evolution theory
SUPERORDINATE CONCEPT - PHENOMENON* Something that is observed or perceived to occur. <u>*Evolution in life forms*</u>	The phenomenon of evolution* refers to changes [modifications] over successive generations in the hereditary characteristics (traits) of populations (groups) of organisms* or life forms* such as viruses*, viroids* and prions* that are related by descent (lineage) and which extends to and includes all levels in the organisation spectrum from genetic systems* to ecosystems*. <u>Life forms* (bionts)</u>* are entities with capabilities for agency and the management, representation and processing of information that allow them *per se* to perform and exhibit the essential properties and characteristics of life, which are organisation* and self regulation*, metabolism*, responsiveness*, movement*, growth*, development*, reproduction*, life-cycling *and evolutionary adaptation (evolvability*). Cellular* organisms express these properties and characteristics directly. Sub-cellular life forms (viruses*, viroids* and prions*) manipulate the cellular machinery of cellular organisms to express these properties and characteristics. <u>Coevolution</u>* concerns reciprocal evolution in interacting species within ecosystems* where changes in one species affects evolution in other species*. The precising definition of species* is central to the concept of coevolution. <u>Microevolution* and macroevolution</u>* are terms used in biology. The ontology centres on microevolution* which applies to evolution or descent with modification due to natural selection within species of life forms and which is marked by changes in their informational molecules. The action of microevolution over time leads to macroevolution and the emergence of new species and extensions to taxonomic groups.

STRUCTURE OF ONTOLOGY according to concept hierarchy	Components within successive levels of the concept hierarchy for evolution theory
SUBORDINATE CONCEPT 1 - THEORY* *The Theory of Evolution by Natural Selection*	The theory of evolution by natural selection* is a well-supported scientific explanation for the diversity of life and proposes that populations of life forms from species to ecosystems evolve over time through the differential survival and reproduction of individuals with heritable traits that confer advantages in a given environment and which can be used to make predictions about natural events or phenomena that have not yet been observed.
SUBORDINATE CONCEPT 2 AGENCY* That by which something is done or achieved. *Natural selection*	Natural selection* is the process* that occurs when organisms or biological entities such as viruses and prions interact with their environment according to their Nature A (essence)*, or intrinsic characteristics and properties, and that of their environment and its biotic and abiotic elements. Natural selection results in 'descent with modification' or generational change whereby forms of organisms or biological entities in a population that are appropriately adapted (fitted) to an environment increase in frequency relative to less well adapted forms. The process of natural selection works through a means likened to a passive filter where elimination and selection of phenotypes according to their viability* and reproductive success (fitness*) results in elimination and selection of the associated genotypes (precising definition).
SUBORDINATE CONCEPT 3 CAUSATION UNIT* Factors that provide for agency.	A causation unit* is a system of overlapping and interacting causal factors or components causes* (compound of component causes) that impel agency and derive from the capabilities associated with life. Darwin named the capabilities that impel natural selection as the 'laws [factors] acting around us' and listed these as: (1) 'growth with reproduction', which arises from the nature A (essence) of the life; (2) 'inheritance which is almost implied by reproduction', which arises from the nature A (essence) of the life form; and (3) variability from the indirect and direct action of the external conditions of life and which arises from both the nature A (essence) of the life form and the nature A (essence) of the environment.
SUBORDINATE CONCEPT 4 CAUSATION UNIT Subset A Factors within the nature (essence) of the environment.	The environment comprises the physical, chemical and biotic factors (including climate, soils and living things) that act on the fitness* of life forms and communities of life forms and determine their survival, form* and function*. 1. *The abiotic environment** includes (1) climatic factors (e.g. temperature, precipitation and humidity, wind patterns,seasonality and solar radiation), (2) geological and edaphic or soil-related factors (soil; composition, texture, drainage, pH, mineral availability; and tectonic activity), (3) hydrological factors (water availability, salinity, pH, dissolved basses, turbidity and light penetration, currents and tides), (4) topographical and structural factors (altitude and air pressure, landscape fragmentation, slope and aspect), (5) chemical and atmospheric factors (oxygen and carbon dioxide levels, nitrogen and phosphorus availability, air quality and pollution, greenhouse gasses and climate change), and (6) planetary and cosmic factors (earth's magnetic field, meteorites, lunar cycles). 2. *The biotic environment* includes (1) intraspecific interactions (competition*, cooperation*, reproductive interactions), (2) interspecific interactions (predation*, herbivory*, parasitism*, mutualism*, commensalism*, amensalism*, competition*), (3) microbial interactions (microbiomes*, pathogens*, horizontal gene transfer*), (4) community level interactions (keystone species*, ecosystem engineering*, niche construction*). 3. *Anthropogenic factors** such as warfare, deforestation and habitat destruction, heat islands, unsustainable land used practices, climate change, animal and plant breeding practices.

STRUCTURE OF ONTOLOGY according to concept hierarchy	Components within successive levels of the concept hierarchy for evolution theory
SUBORDINATE CONCEPT 5 CAUSATION UNIT Subset B Factors within the <u>nature (essence) of the life form</u>.	Natural selection acts on the nature of life forms through capabilities* for viability* and reproduction*, which together constitute fitness* and which arise from the processes* of physiology or workings of a life form and associated adaptations*. <u>Capability</u>* is the quality or property of being capable or having ability. <u>A process</u>* is particular method method of doing, achieving or arriving at something and generally involves a sequence of steps. <u>An adaptation</u>* is any peculiarity, property or feature of the structure, physiology or behaviour of a life form that enables it to survive and reproduce in a particular environment. <u>Processes and adaptations</u> operate through the organisation* of structures*, functions* and mechanisms* in a life form. <u>Organisation</u>* refers to the ordered arrangement and interaction of components within a system that determines how structures*, functions* and mechanisms* integrate to produce capabilities* that generate agency* or the means by which something is achieved. <u>Structure</u>* is the manner by which the physical components of a whole are organised. <u>Function</u>* refers to the normal or characteristic action of anything such as the actions operating in life life forms. <u>Mechanism</u>* is the way something works.

Note that Table 14 refers to a precising definition for species, which can expedite an understanding of the processes leading to continual emergence of the epidemic and pandemic viral diseases that confront One Health. The precising definition extends to viruses and depicts species as discrete populations of life forms that possess communal properties for unrestricted and effective reproduction. Mutation rates in viruses vary according to the nature of their informational macromolecules and mutation rates in single-stranded RNA viruses such as the influenza, MERS, SARS CoV-1 and SARS CoV-2 viruses can be prodigious. Two sources of mutation are in play in these single-stranded RNA viruses. First is the absence of proof-reading mechanisms that govern the fidelity of genome replication in other life forms. Second is genome mixing which requires so-called mixing vessel hosts (Scholtissek, 1987; Yasuda, 1991; Abdelwhab and Mettenleiter, 2023). Mixing vessel host allow concurrent infections with different subpopulations of the same species of a virus and the consequent blending of genomes. As a result, mixing vessel hosts generate new viral subpopulations with new capabilities including extended host ranges, increased virulence, new modes of transmission and longer persistence in the environment. Humans, pigs, minks, ferrets, seals, dogs, cats, and birds, particularly turkeys, chickens, quails, and ducks, are probable mixing vessel hosts for avian influenza viruses (Abdelwhab and Mettenleiter, 2023).

Table 14: Alphabetical list of precising definitions of terms and concepts that apply directly or indirectly to the ontology for evolution theory as shown in Figure 9.

Term or concept	**Precising definition**
Abiotic (as in abiotic environment)	Related to the physical world.

Term or concept	Precising definition
Adaptation	Any peculiarity, property or feature of the structure, physiology or behaviour of an organism or biological entity, such as a virus or prion, that enables it to survive and reproduce in a particular environment. Adaptations can be depicted as the capabilities that underpin viability and reproduction.
Allele/allelomorph	Refers to either of the two alternative forms of a gene occupying the same site (locus) in genomes of life forms that reproduce sexually.
Amensalism	An association between organisms where one population is inhibited and the other population is unaffected.
Anthropogenic factor	Factors arising from the activities of humankind.
Biont	A discrete unit of living matter and a term that covers cellular organisms and subcellular life forms (viruses, viroids, virusoids and prions).
Biotic (as in biotic environment)	Related to life, life forms and the living world.
Capability/ability/capacity	<u>Capability</u>: The quality of being capable or having ability. <u>Ability</u>: Being able, power to do. <u>Capacity</u>: The quality of of being adapted for something.
Cause/causation	<u>Cause</u> (noun): Anything making something happen or exist an effect or result. <u>Cause</u> (verb): To make something happen or exist. <u>Causation</u>: The act of causing or causal agent.
Causation unit	The organisation of component causes (namely; processes, capabilities, adaptations, structures, functions and mechanisms) that allow for agency or the way something is done or achieved.
Cell/cellular	The basic structural building block of living organisms, consisting of protoplasm delimited by a cell membrane that produces an open thermodynamic unit able to regulate the exchange of matter and energy with the surrounding environment.
Coevolution	Reciprocal evolutionary change among interacting species driven by natural selection.
Commensalism	Association between two organisms or life forms of different species that live together and share food resources, one species benefiting from the association and the other not being harmed.
Competition	<u>Direct inhibition type</u>: An interaction between species in one population actively inhibits the other perhaps through allelopathy, antibiosis or bacteriocins. <u>Resource use type</u>: An interaction between species in which each population adversely affects the other indirectly in the struggle for resources in short supply.
Component cause	A component cause is an event or condition that contributes to the development of a disease, but is not sufficient on its own to cause the disease. Component causes make up the causal pie model for disease causation.
Concept hierarchy	Concepts are ideas or mental images that correspond to some distinct entity or class of entities, or to its essential features, and determines the application of a term in language and reasoning. Concepts can be arranged or ranked as hierarchies. Superordinate concepts at higher levels cover a broader scope than the subordinate concepts at lower levels. . Concept categories are essential foundations for the ontologies used to drive information technology.
Cooperation	See mutualism.
Development	Process by which an organism grows and changes from a single cell (as in a zygote) into a mature, multicellular individual and which involves cell division, cell differentiation, and the consequent generation of the structures and functions that characterise life.
Ecosystem	Community of different species interdependent on each other, together with their non-living environment, which is relatively self-contained in terms of energy flow, and is distinct from neighbouring communities. Different types of ecosystem are defined by the collection of organisms found within them, e.g. forest, soil, grassland.

Term or concept	Precising definition
Ecosystem engineering	Process by which organisms directly or indirectly modify, maintain, or create habitats, thereby altering the availability of resources for other species.
Epigenetics	Refers to phenomena in structure, function an behaviour in life forms due to alterations in DNA that do not include changes in the base sequence and which often affect the way in which DNA sequences are expressed. Such alterations can be stable and heritable in the sense that they are passed to descendant cells or individuals. Relates to expressivity as in gene expression and penetrance.
Eukaryote	Organism with genetic material contained within a circumscribed nucleus in its cells.
Evolution	Refers to changes [modifications] over successive generations in the hereditary characteristics (traits) of populations (groups) of organisms or life forms such as viruses, viroids and prions that are related by descent (lineage) and which extends to and includes all levels in the organisation spectrum from genetic systems to ecosystems. The phenomenon of evolution is driven by the process of natural selection.
Evolvability	Capacity to undergo evolutionary change. The presence of heritable variation in an organism, virus or prion that can be subjected to natural selection.
Fitness	Success of an organism at surviving [that is, being viable] and reproducing and thus contributing offspring to future generations.
Form	The way the physical components of a whole are organised.
Function	Specific role or activity performed by a structure, molecule, or process that contributes to the viability of a life form. Activity and role assigned to something.
Gene	Denotes the basic unit of heredity and has a physical manifestation in the chemical structure of the informational macromolecules that make up the genome of a life form, and which can be DNA (deoxyribonucleic acid), RNA (ribonucleic acid) or protein in the case of prions. Genes contain the instructions for making a specific protein or set of proteins (precising definition).
Genetics	The biological discipline concerned with the study of genes, genetic variation, and heredity in life forms.
Genetic system	The entirety of genes within a life form and the processes that regulate the expression and inheritance of these genes.
Genome	Genomes are the entire set of genes specified in physical form by the associated set of informational macromolecules that predominate in a life form. For eukaryotic organisms, this includes both nuclear and mitochondrial DNA.
Genotype	The genotype mirrors the genome and refers to the genetic composition of a life form.
Growth	Refers to an increase in size and mass of a life form as a result of cell division and enlargement. The process is irreversible and leads to the final physical form and structure of a life form.
Herbivory	A form of nutrition in which life form principally eats autotrophs such as plants, algae and photosynthesising bacteria. Autotrophs are life forms that produce their own food by means of light, water, carbon dioxide and other chemicals.
Heritability	The capability of genetic material and its associated information for being transmitted from generation to generation (precising definition).
Holobiont	Holobiont life forms, exemplified by ruminant mammals, comprise a host with its associated population of endosymbiotic life forms which operate harmoniously to support the existence of all participants.
Horizontal gene transfer (lateral gene transfer)	The transfer of genetic material and information among life forms by means other than the process of reproduction and transmission of genetic material and information from parent to offspring in a single given species. Horizontal gene transfer may involve mobile genetic elements such as plasmids, prophages, pathogenicity islands, restriction and modification systems, transposons, and insertion sequences.
Inheritance	Transmission and reception of genetic information from generation to generation via

Term or concept	Precising definition
	processes of reproduction.
Irritability (see responsiveness)	Ability of a life form to respond to environmental stimuli. Irritability is co-extensive with responsiveness and sensitivity.
Keystone species	A life form that plays a crucial role in maintaining the structure and function of its ecosystem and not necessarily the most abundant species in that ecosystem.
Life cycling/life cycle	Refers to the sequence of changes in a life form as it passes from a given developmental to the same developmental stage in the following generation.
Life (life form)	Life as a phenomenon is present in life forms and living systems and entails capabilities for agency and information management that control the transformations of energy and material necessary for vital functions or processes that actuate, implement and sustain the phenomenon. Capabilities for agency and information management enable eukaryotic and prokaryotic cellular organisms to employ their intrinsic cellular machinery and implement *per se* an overlapping, interrelated and comprehensive set of vital functions comprising various forms of organisation, self-regulation, nutrition, metabolism (transformations of matter and energy), respiration, excretion, responsiveness, homeostasis, movement, life-cycling (growth, development and reproduction) and evolutionary adaptation. Capabilities for agency and information management enable sub-cellular life forms, organic beings or bionts (exemplified by viruses and prions) to associate with prokaryotes and eukaryotes and exploit the comprehensive and set of vital functions in these cellular organisms to implement the particular vital functions of reproduction and evolutionary adaptation. Associations with viruses or prions can range from beneficial to harmful for cellular organisms.
Macroevolution	Evolutionary change over relatively long time periods due to natural selection in life forms and changes in their informational macromolecules (i.e. microevolution) and which leads to the emergence of new species and extensions to taxonomic groups.
Mechanism	The way something works or an instrument or a process, physical or mental, by which something is done or comes into being.
Microbiome	Entire community of microbes such as bacteria (monerans), archaea, fungi, viruses, and protistans that live in a particular environment plus their collective genetic material.
Microevolution	Evolution or descent with modification due to natural selection within species of life forms and marked by changes in their informational molecules. The action of microevolution over time leads to macroevolution and the emergence of new species and extensions to taxonomic groups.
Movement	Change in the position of an organism, a body part, or a cell over time. It includes voluntary and involuntary actions and is a fundamental characteristic of all life forms.
Mutualism	A type of interaction between two or more species in which growth and survival of all populations is benefitted and none alone can survive under natural conditions. Mutualism operates in holobionts such as ruminants.
Mutation	An alteration in the genetic material (the genome) of a cellular organism or virus that can pass from one generation to another. Mutations are a source of diversity that drives evolution. Mutations may occur as large-scale changes such as the loss or rearrangement of a large section of a chromosome or as small-scale changes where there is a substitution, insertion or deletion of one or more nitrogenous base pairs in a section of DNA, or in the case of viruses in nitrogenous bases within sections of either DNA or RNA. Mutations in genetic material alter amino acid sequences in proteins and thus affect viability through gains-of-function or losses-of-function. Frameshift mutations are those where added or deleted nitrogenous bases disrupt the reading frame that guides the processes of transcription and translation. Mutations can occur as copying errors during the replication of informational macromolecules (DNA or RNA) or can be the result of exposure to mutagens.
Nature/natural	Nature (natural) can refer to the intrinsic character of a person or thing (Nature A - Essence), the forces controlling the physical world (Nature B - Forces) or the physical

Term or concept	Precising definition
	world itself (Nature C – Physical World). The ontology for evolution theory focusses firstly on Nature A (Essence) and secondly on Nature C (Physical World).
Natural selection	Natural selection is the process that occurs when organisms or biological entities such as viruses and prions interact with their environment according to their nature, or intrinsic characteristics and properties, and that of their environment and its biotic and abiotic elements (Nature A - Essence). Natural selection results in 'descent with modification' or generational change whereby forms of organisms or biological entities in a population that are appropriately adapted (fitted) to an environment increase in frequency relative to less well adapted forms. The process of natural selection works through a means likened to a passive filter where elimination and selection of phenotypes according to their viability results in elimination and selection of the associated genotypes. The process of natural selection drives the phenomenon of evolution.
Niche	In ecology, niche refers the position of a species within an ecosystem and the range of conditions necessary for its persistence and activities. Ecological niches entail all interactions between a species and its abiotic or physical environment and its biotic environment which involves associations among species ranging from predation to cooperative mutualism and which extends to the trophic level occupied by a given species in the food chain and food webs. Two-way interactions occur where the environment affects a species and a species affects its environment and in doing so affects other species.
Niche construction	1. The process whereby organisms, through their metabolism, their activities, and their choices, modify their own and/or each other's niches. 2. A process of involving reciprocity and where organisms alter conditions in their surrounding environment and where the changed conditions impose a selection pressure on other organisms.
Organisation	Refers to the ordered arrangement and interaction of components within a system that determines how structures, functions and mechanisms integrate to produce capabilities that generate agency or the means by which something is achieved.
Organism	A living thing that can function independently and perform all processes necessary for life. Organisms can be unicellular like bacteria and multicellular organisms like plants and animals. Organisms possess capabilities for growth, development, reproduction, responsiveness to stimuli, and the maintenance of a stable internal environment
Parasitism/parasite	A symbiotic association between two life forms where one life form, the parasite, benefits at the expense of another organism, the host.
Pathogen	A living agent (germ) capable of producing disease in another life form.
Prion	Prions are misfolded proteins arising from failed proteostasis that can trigger other normal proteins to misfold and lead to a cascade of misfolding and consequent disease. Prions can be transmissible and are the causative agents of the rapidly progressive neurodegenerative diseases known as the transmissible spongiform encephalopathies. Prions are implicated in other degenerative diseases such as Alzheimer's disease, Parkinson's disease and the non-transmitting form of scrapie disease in sheep.
Process	A particular method of doing, achieving or arriving at something, generally involving a number of steps or operations.
Prokaryote	Organism with cells where the genetic material is not enclosed within a circumscribed nucleus.
Regulation/self-regulation/autopoiesis	Autopoiesis (term coined by Maturana and Varela, 1972) refers to the self-producing, self-maintaining, self-repairing and self-relational aspects of living systems.
Replication	Replication refers to the duplication of informational macromolecules by life forms (including viruses and prions whereas reproduction refers to the processes by which life forms give rise to new individuals of their kind.
Reproduction	Reproduction is the process by which life forms from viruses to monerans, protistans, fungi, plants and animals generate new individuals of the same kind, ensuring the continuity of life in their species. Reproduction can be asexual with one parent and

Term or concept	Precising definition
	identical offspring or sexual with two parents and genetically varying offspring.
Responsiveness	Capacity of life forms to adjust and adapt to changes in both their internal and external environments and by means of physiological and behavioral mechanisms. Responsiveness is co-extensive with irritability and sensitivity.
Sensitivity	A life forms ability to detect and respond to stimuli in its environment. Sensitivity is co-extensive with responsiveness.
Species	Species are discrete populations of organisms (some of which are holobionts) or sub-cellular and non-organismal entities such as viruses, viroids, viusoids and prions, that share structural and functional characteristics. Some of these characteristics implement and control the exchanges (vertical or horizontal) and propagation of genetic material as whole genomes through successive generations and thus create barriers to reproduction and opportunities for reproduction that demarcate one discrete population from another. Species contain subsets or subpopulations with diverse capabilities that constitute variation.
Structure (form)	Structure: The arrangement or interrelation of all the [physical] parts of a whole or a system or organisation made up of interrelated parts that function as an orderly whole. Form: The way the physical components of a whole are organised.
Symbiosis	The close and usually obligatory association of two or more life forms of different species living together, not necessarily to their mutual benefit.
Theory (in science)	Theories are comprehensive explanations of aspects of nature that are supported by vast bodies of evidence such that they can be used to make predictions about natural events or phenomena that have not yet been observed. Theories can be refined in the light of new knowledge.
Theory of evolution by natural selection	The theory of evolution by natural selection is a well-supported scientific explanation for the diversity of life and proposes that populations of life forms from species to ecosystems evolve over time through the differential survival and reproduction of individuals with heritable traits that confer advantages in a given environment and which can be used to make predictions about natural events or phenomena that have not yet been observed.
Viability	Depicted for organisms, as the capability for life, being alive or living. For biological entities such as viruses and prions viability is depicted as the capability for existing and executing life cycles based on propagation within organisms and transmission among organisms.
Viroid	Small, circular, single-stranded RNA molecules without a protein coat that infect plants and cause disease. Viroids rely on the cellular machinery of the host plant for replication.
Virus	Viruses are submicroscopic infectious agents, non-organismal biological entities and obligate intracellular symbionts with life cycles entailing capabilities and structures for reproduction within hosts and transmission between hosts. The virion which consists of informational macromolecules (DNA or RNA in various forms that constitute an evolvable genome), a capsid or protein coat and sometimes an envelope or lipoprotein outer covering is the extracellular stage of viruses that mediates infection in hosts and transmission from host to host. Viruses reproduce within hosts by employing information encoded in their genomes to harness intracellular processes for transforming matter and energy.
Virusoid	Subviral particle and type of satellite RNA that infects plants. Virusoids consist of a small, single-stranded, circular RNA molecule and differ from viroids by needing a helper virus for replication and spread.

A closing note is that an ontology for evolution theory can pave the way towards the enhanced application of this theory and its union with germ theory and cell theory within One Health and in a manner that meets the needs and expectations of a wide audience, addresses linguistic barriers and the open science ideal of UNEP's sustainable development goals. The ontology has possible utility within freely accessible global knowledge bases such as the AGROVOC and AIMS initiatives of

FAO. AGROVOC and AIMS seek to mitigate language barriers, improve access to knowledge and assist towards global food production and security. One Health extends to the conservation and management of natural resources and encompasses the sustainable development goals (SDGs) promulgated by the United Nations Environment Programme (UNEP). The ontology can also assist in overcoming the language barriers that impede progress in these areas (Fettes, 2022; Piczak et al., 2022; Amano and Berdejo-Espinola, 2025).

A way forward may be to demonstrate the utility of the ontology for evolution theory by means of a detailed explanation of how it can create a conceptual framework for understanding the factors and circumstances that lead to the emergence and re-emergence of epidemic and pandemic diseases such as those caused by coronaviruses, influenza viruses, the monkeypox virus, hantaviruses and so on. A conceptual framework of this sort constitutes a potent analytical tool for One Health field workers and planners and could assist in achieving the aims and aspirations of the WHO pandemic agreement which was proposed in 2024 (WHO, 2024) and adopted on 20th May 2025[105]. This venture by the WHO addresses a conspicuous need and includes measures for collaborative surveillance using a One Health approach and refers to 'joint training and continuing education programmes for human, animal and environmental health workforces to build relevant and complementary skills, capacities and capabilities'. The WHO pandemic agreement seeks for global solidarity and continues the theme of global solidarity espoused by the Preparedness and Resilience for Emerging Threats (PRET) initiative of the World Health Organization (WHO 2023, https://www.who.int/initiatives/preparedness-and-resilience-for-emerging-threats) and the quadripartite One Health Joint Plan of Action (OH JPA, 2022–2026) of the FAO, UNEP, WHO, and WOAH (2022).

[105] https://www.who.int/news/item/20-05-2025-world-health-assembly-adopts-historic-pandemic-agreement-to-make-the-world-more-equitable-and-safer-from-future-pandemics

Appendices

Appendix 1. Definition of One Health and Key Underlying Principles from the OHHLEP (One Health High-Level Expert Panel), 2022

One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent.

The approach mobilizes multiple sectors, disciplines, and communities at varying levels of society to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for healthy food, water, energy, and air, taking action on climate change and contributing to sustainable development.

Key underlying principles

1. **equity** between sectors and disciplines;
2. sociopolitical and multicultural **parity** (the doctrine that all people are equal and deserve equal rights and opportunities) and inclusion and engagement of communities and marginalized voices;
3. socioecological **equilibrium** that seeks a harmonious balance between human– animal–environment interaction and acknowledging the importance of biodiversity, access to sufficient natural space and resources, and the intrinsic value of all living things within the ecosystem;
4. **stewardship** and the responsibility of humans to change behavior and adopt sustainable solutions that recognize the importance of animal welfare and the integrity of the whole ecosystem, thus securing the well-being of current and future generations; and
5. **transdisciplinarity** and multisectoral collaboration, which includes all relevant disciplines, both modern and traditional forms of knowledge and a broad representative array of perspectives.

Appendix 2. Dictionary Definitions of Selected Words that Require Clear-cut Meanings within the Ontology for theory of evolution by natural selection

Plain meanings for a set of crucial words underpin the present quest for an intelligible bridge between evolutionary biology and One Health. These words and their plain meanings are used, firstly, in the survey of word use in the influential literature on evolution and, secondly, to guide the ontology for theory of evolution by natural selection based on contemporary biology and disciplined by practices in computer science, software engineering with their subset known as artificial intelligence. The initial prompt for a concentrated exploration of these words came from the word ‘theory’, which has multiple meanings and a specific and cardinal meaning in the practice of science (section 2.4). Confusion around the word ‘theory’ and other important words is prevalent in influential works on evolutionary biology and has particularly profound implications when the goal is extension of science across language barriers.

Table 4 in section 3.1 sets out a list of words selected for their prominence in theory of evolution by natural selection and their utility in the concept scheme or framework for natural selection theory. These words are arranged in four *ad hoc* categories as follows: 1. Words relating to general ideas, 2. Words in general use that extend to the living world, 3. Figurative language used by Darwin in lieu of contemporary biological terms and concepts, and 4. Terms used in biology and absent from Darwin’s *Origin of Species*. Table 5 in section 3.1 shows data from concentrated exploration of the words Nature [Natural] and Theory.

The four tables below show data from a concentrated exploration of all words set out in the four *ad hoc* categories of Table 4. The first column shows the multiple denotative and connotative meanings of each words according to contemporary usage as described by the Encarta World English Dictionary (Rooney, 1999). This dictionary was selected because it focuses on the English language as an open and universal resource (World English; McArthur, 1999) that can realise the principle of universalism in science (Merton, 1972) and provide common and open access to information for the international community (UNESCO, 2005). The second column shows when the words came into common use as recorded in two early editions of Webster's Dictionary (Webster, 1842 and Webster, Goodrich and Porter 1865) and the Oxford English Dictionary (Murray et al., 1888 and Simpson and Weiner, 1989) to give a view of word usage in Darwin's lifetime. Various other versions of Webster's Dictionary and the Oxford English Dictionary (A New English Dictionary on Historical Principles: Founded Mainly on the Materials Collected by the Philological Society) were consulted via the website archive.org. Columns three and four list where each word occurs in the semantic fields or synonym clusters found in the Penguin Roget’s Thesaurus (Lloyd, 1984) and the Macquarie Thesaurus (Bernard, 1984). The purpose here is

to cross-check on ambiguities and inconsistencies of use within the literature on evolutionary biology. The fifth column contains comments deemed to be helpful.

Table 15. Appendix Table A1: Dictionary meanings of words related to general ideas that apply in the ontology for evolution theory.

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meanings**	**Keyword and semantic fields: The Penguin Roget's Thesaurus**	**Keyword and semantic fields: Macquarie Thesaurus**	**Comments**
Behave [behaviour]	1. ACT: To act in a particular way that expresses general character, state of mind, or response to a situation or other people. 2. BEHAVE WELL: to act in an acceptable way, especially by being polite, good-tempered and self-contolled. 3. PERFORM: To perform or react to particular conditions, or operate in accordance with natural laws	Lexico gives a definition of behave that is apt for the present endeavour: (of a machine or natural phenomenon) to work or function in a specified way. This definition is not apparent in Webster's Dictionary 1828, or the New English Dictionary of 1888.	Behave *behave* 688 vb. *be virtuous* 933 vb. Behaviour *mien* 445 n. *conduct* 688 n.	Behave vb. and behaviour n. CONDUCT/ MISCONDUCT 124 *conduct*	Meaning 3 of behave (PERFORM) apt for the present endeavour. Put simply, behaviour is what organisms and biological entities such as viruses, viroids and prions do. Section 4.2.3 gives a biological definition of behaviour.
Capability [capable]	1. COMPETENCE: the ablity necessary to do something. 2. TALENT THAT COULD BE DEVELOPED: an ability or characteristic that has potential for development. 3. POTENTIAL FOR USE: the potential to be	Webster's Dictionary 1828: **CAPABILITY**, *noun* [See Capable.] The quality of being capable; capacity; capableness. **CAPABLE**, *adjective* **1.** Able to hold or contain; able to receive; sufficiently capacious; often followed by of; as, the room is not	Capability *ability* 160 n. *skill* 694 n. Capable *possible* 469 adj. *intelligent* 498 adj.	Capability COMPETENCE/ INCOMPETENCE *ability* 113.1 *competent* 113.4 POWER/IMPOTENCE *capacity* 568.2 *capable* 568.6	*Origin of Species* contains no mention of 'capability' and mentions 'ability' twice in reference to people.

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus	Keyword and semantic fields: Macquarie Thesaurus	Comments
	used for a particular purpose or treatd in a particular manner.	*capable* of receiving, or *capable* of holding the company. **2.** Endued with power competent to the object; as, a man is *capable* of judging, or he is not *capable* **3.** Possessing mental powers; intelligent; able to understand, or receive into the mind; having a capacious mind; as a *capable* judge; a *capable* instructor. **4.** Susceptible; as, *capable* of pain or grief. **5.** Qualified for; susceptible of; as, a thing is *capable* of long duration; or it is *capable* of being colored or altered.			
Capacity	1. MENTAL OR PHYSICAL ABILITY: The ability to do or experience something. Seven other meanings are given but are deemed	Webster's Dictionary 1828: CAPACITY, noun **3.** Active power; ability; applied to men or things; but less common, and correct.	*plenituude* 54 n. *inclusion* 78 n. *ability* 160 n. *room* 183 n. *size* 195 n. *intelligence* 498 n. *function* 622 n.	Relevant entries are under headings of POWER/IMPOTENCE *capacity* 568.2 COMPETENCE/ INCOMPETENCE *ability* 113.1	Eight meanings pf 'capacity' are listed in Encarta Dictionary of World English: Meaning 1 is the only meaning deemed relevant for present purposes.

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meanings**	**Keyword and semantic fields: The Penguin Roget's Thesaurus**	**Keyword and semantic fields: Macquarie Thesaurus**	**Comments**
	irrelevant for present purposes.			*competent* 113.4	
Concept and conception	SOMETHING THOUGHT OR IMAGINED: something that somebody has thought up or that somebody might be able to imagine. BROCE PRINCIPLE AFFECTING PERCEPTION AND BEHAVIOUR: A broad abstract idea or a guiding general principle, such as one that determines how a person or culture behaves, or how nature, reality or events are perceived: UNDERSTANDING OR GRASP, the most basic understanding of something. WAY OF DOING OR PERCEIVING SOMETHING: a method, scheme, or type of product or design.	Webster's Dictionary 1865, corroboration OED 1989.	*idea* 451n *imagination, ideality* 513n *thought* 449n	*Tangible/the intangible, abstraction* 737.1 *Notion* 497.1	'Concept' is a synonym for Theory B - 'idea'. The word 'concept' was not found in Webster's Dictionary before1865 and may have been referred to as 'conception'.

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meanings**	**Keyword and semantic fields: The Penguin Roget's Thesaurus**	**Keyword and semantic fields: Macquarie Thesaurus**	**Comments**
Doctrine	RULE OR PRINCIPLE: a rule or principle that forms the basis of a belief, theory or policy. IDEAS TAUGHT AS TRUTH: a body of ideas, particularly in religion, taught to people as truthful or correct. Something taught to people.	Webster's Dictionary 1828, corroboration OED 1989.	*belief, creed* 485n *religion, theology* 973n	*Credence/* *Doubt Creed* 152.2 *Instruction Teachings* 399.4 No overlap in meaning with Theory A	'Doctrine' differs in meaning from Theory A (Science). Doctrine implies authority rather than fact and reality and is out of step with the organised scepticism of science (Merton, 1942).
Evolution	*BIOL* THEORY OF DEVELOPMENT FROM EARLIER FORMS: The theoretical process by which all species develop from earlier forms of life. On this theory, natural variation in the genetic material of a population favours reproduction by some individuals more than others, so that over the generations all members of the population come to possess the favourable traits. *BIOL* DEVELOPMENTAL PROCESS: The natural or	Webster's Dictionary 1828, EVOLUTION, noun [Latin evolutio.] The act of unfolding or unrolling. 1. A series of things unrolled or unfolded; as the evolution of languages.	*conversion* 147n *motion* 265n *progression* 285n *biology* 358n	*development* 602.2 *evolution* 225.1 *growth* 335.1	Selected contemporary definitions of 'evolution' are given in Table 1 in section 2.

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus	Keyword and semantic fields: Macquarie Thesaurus	Comments
	artificially induced process by which new and different organisms develop as a result of changes in genetic material. GRCEUAL DEVELOPMENT: The gradual development of something into a more complex or better form – *the evolution of democracy in Western Europe,*				
Function	Noun 1 PURPOSE: An action or use for which something is suited or designed. Verb 1. SERVE PURPOSE: To serve a particular purpose or perform a particular role. 2. BE IN WORKING ORDER: to operate normally, performing a particular role.	From Webster (1828) **1.** In a general sense, the doing, executing or performing of any thing; discharge; performance; as the *function* of a calling or office. **4.** The office of any particular part of animal bodies; the peculiar or appropriate action of a member or part of the body, by which the animal economy is carried on. Thus we speak of the functions of the brain and nerves, of the heart, of the liver, of the muscles, etc.	*number* 85 n. *operate* 173 vb. *function* 622 n. vb. *do* 676 vb. *celebration* 876 n.	FUNCTION 280.1 function USE/DISUSE 773.2 function DOING 185.2 process	Encarta World Dictionary lists 10 different meanings for Function (noun). Meaning 1 is the only one deemed relevant for present purposes. From Blakiston's New Gould Medical Dictionary (Hoerr and Osol, 1956): Function: The normal or special action of a part.

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus	Keyword and semantic fields: Macquarie Thesaurus	Comments
Hypothesis	THEORY NEEDING INVESTIGATION: a tentative explanation for a phenomenon used as a basis for further investigation. ASSUMPTION: a statement that is assumed to be true for the sake of argument.	Webster's Dictionary 1828, corroboration OED 1989.	*belief, opinion, hypothesis* 485n	*Congruity/Incongruity, assumption* 131.2 *Subject matter (hypothesis)* 720.2 *Conditionality/ Unconditionality-precondition* 122.1	'Hypothesis' is a synonym for Theory B (Idea).
Mechanism	2. SOMETHING LIKE A MACHINE: Something that is not a machine	From Murray et al. (1888) – New English Dictionary. 1. The structure or mutual adaptation of parts, in a machine or anything comparable to a machine, whether material or immaterial. (In early use chiefly with reference to natural objects). 2. *concr.* A system of mutually adapted parts working together mechanically or in a manner analogous to mechanical action; a piece of machinery; the machinery (*lit.* or *fig*.) by means of which some particular effect is produced. Also, machinery or mechanical appliances in general.	*machine* 630 n.	MECHANICAL DEVICES 468.1 PROCEDURE 479.1 process	From Blakiston's New Gould Medical Dictionary (Hoerr and Osol, 1956): Mechanism: 1. An aggregation of parts arranged in a mechanical way to perform a specific function. 2. The manner in which a mechanical act is is performed, as in the mechanism of labor.

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meanings**	**Keyword and semantic fields: The Penguin Roget's Thesaurus**	**Keyword and semantic fields: Macquarie Thesaurus**	**Comments**
Nature A (Essence) Also Natural A	INTRINSIC CHARACTER OF PERSON OR THING; the intrinsic or essential character of somebody or something [the inherent character or basic constitution of a person or thing – Merriam Webster Dictionary]	Webster's Dictionary 1828, corroboration OED 1989.	*Intrinsicality character* 5n	*Nature (Essence)* 222.2 *Character* 89.1	Nature A (Essence) is the denotation of nature employed in the ontology for theory of evolution by natural selection designed as a user interface within One Health.
Nature B (Forces) Also Natural B	FORCES CONTROLLING THE PHYSICAL WORLD; The forces and processes collectively that control the phenomena of the physical world independently of human volition or intervention.	Webster's Dictionary 1828, corroboration OED 1989.	Not present	Not present	Nature B (Forces) is the meaning that applies to Darwin's conception of natural selection. From page 63 of *Origin of Species*: '*….but I mean by Nature, only the aggregate action and product of many natural laws, and by laws the sequence of events as ascertained by us'*.
Nature C (Physical World)	PHYSICAL WORLD: The physical world including all natural phenomena and living things.	Webster's Dictionary 1828, corroboration OED 1989.	*Production, producer* 164n *Materiality, matter* 319n	*Organism, biota* 522.2 *Cosmos (Cosmos)* 146.1 *Cosmos (Tangible)* 736.1 *Life* 447.1 *Nature (Nature)* 494.1	

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus	Keyword and semantic fields: Macquarie Thesaurus	Comments
Perform [performance]	1. ACCOMPLISH: to carry out an action or accomplish a task. 2. FULFIL: To do what is stated or required. 3. *vti*. ARTS: Present an artistic work. 4. vi. FUNCTION OR BEHAVE: To function, operate or behave in a particular way or to a particular standard.	Webster's Dictionary 1828: **1.** To do; to execute; to accomplish; as, to *perform* two days' labor in one day; to *perform* a noble deed or achievement. **2.** To execute; to discharge; as, to *perform* a duty or office. **3.** To fulfill; as, to *perform* a covenant, promise or contract; to *perform* a vow.	*act* 594 vb. *be instrumental* 628 vb. *do* 676 vb. *observe* 768 vb, (sense of heed).	v. *accomplish* 6.6 *complete* 801.6 *do* 185.7 *fulfil* 185.5	Performance (noun) 2. MANNER OF FUNCTIONING: The manner in which something or somebody functions, operates or behaves. The selective breeding of plants as animals selects on the basis of observation – including performance in things like milk production and wool production.
Phenomenon	SOMETHING EXPERIENCED: A fact or occurrence that can be observed. OBJECT OF PERCEPTION: something perceived or experienced, especially an object as it is apprehended by the human senses as opposed to an object as it intrinsically is in itself.	Webster's Dictionary 1828: In a general sense, an appearance; any thing visible; whatever is presented to the eye by observation or experiment, or whatever is discovered to exist; as the phenomena of the natural world; the phenomena of heavenly bodies, or of terrestrial substances; the phenomena of heat or of color. It sometimes denotes a remarkable or unusual appearance.	*event* 154 noun. a*ppearance* 445 noun.	*Occurrence* 507.1 *Phenomenon* 31.1 *Thing* 736.1	Phenomenon will be the superordinate concept in the proposed ontology for natural selection theory. The related word 'fact' has a broader meaning than 'phenomenon'. A fact is something known to be true or the truth or reality of something without specifying the pathway of human senses.

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus	Keyword and semantic fields: Macquarie Thesaurus	Comments
		From Murray et al. (1908) – New English Dictionary. 1. In scientific and general use; a thing that appears , or is perceived or observe, an individual fact, occurrence.			
Process	SERIES OF ACTIONS: a series of actions directed towards a particular aim. SERIES OF NATURAL OCCURRENCES: a series of natural occurrences that produce change or development.	Webster's Dictionary 1828: **PROC'ESS**, *noun* [Latin processus, from procedo. See Proceed.] **1.** A proceeding or moving forward; progressive course; tendency; as the *process* of man's desire. **2.** Proceedings; gradual progress; course; as the *process* of a war. **3.** Operations; experiment; series of actions or experiments; as a chimical *process* **4.** Series of motions or changes in growth, decay, etc. in physical bodies; as the *process* of vegetation or of mineralization; the *process* of decomposition. **5.** Course; continual flux or passage; as the *process* of time. **6.** Methodical management;		*function* 280.1 *process (doing)* 185.2 *process (procedure)* 579.1	

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus	Keyword and semantic fields: Macquarie Thesaurus	Comments
		series of measures or proceedings.			
Progress	IMPROVEMENT: Gradual development or improvement of something. MOTION TOWARDS SOMETHING: Movement forward or onwards.	Webster's Dictionary 1828: Corroboration OED 1989.	*increase* 36n *motion* 265n *progression* 285n *improvement* 654n	*advance* 335.1 *evolution* 225.1 *going forwards* 300.1	Lexico a collaboration with Oxford Dictionary (www.lexico.com) provides the following definition of progress – which implies a value judgement PROGRESS: Development towards an improved or more advanced condition. 'we are making progress towards equal rights'
Proposition	PROPOSAL: An idea, offer, or plan put forward for consideration or discussion. STATEMENT: A statement of opinion or judgment.	Webster's Dictionary 1828, corroboration OED 1989.	*topic* 452n *supposition* 512n	*Assumption* 131.2 *Subject matter (hypothesis)* 720.2 [Other listed keywords not directly relevant]	Possible synonym for Theory B - 'idea'.
prefix: -ism, as in Darwinism	-ISM MEANING 5: Doctrine, system of beliefs. DARWINISM: 1. = Darwinian theory. 2 SUPPORT FOR DARWIN'S THEORY:	Darwinism: Webster's Dictionary 1898 'The theory or doctrines put forward by Darwin'.	*creed* 485 n.	*-ISM* *Credence/Doubt Creed* 152.2 *Conjecture 2; theory* 131.2	Refers to Theory B (Idea) Blakiston's New Gould Medical Dictionary (Hoerr and Osol,1956) describes -ism as a prefix indicating 1. Condition or

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meanings**	**Keyword and semantic fields: The Penguin Roget's Thesaurus**	**Keyword and semantic fields: Macquarie Thesaurus**	**Comments**
	belief in or advocacy for Charles Darwin's theory of evolution.				disease from, as embol*ism*, alcohol*ism. 2.* Doctrine or practice of (often with a corresponding verb ending in -*ize* and noun ending with -i*st*, as Fletcherism, hypnotism). The word Darwinism is incompatible with the meaning of theory in science.
Theory A (Science)	SCIENTIFIC PRINCIPLE TO EXPLAIN PHENOMENA: A set of facts, propositions or principles analysed in their relationship to one another and used especially to explain phenomena [late 16thC] 'comprehensive explanations of aspects of nature that are supported by vast bodies of evidence such that that they can be used to make predictions about natural	Webster's Dictionary 1828, corroboration OED 1989: 'The philosophical explanation of phenomena, either physical or moral; as Lavoisier's *theory* of combustion; Smith's *theory* of moral sentiments. Theory is distinguished from hypothesis thus; a *theory* is founded on inferences drawn from principles which have been established on independent evidence; a h has no other The philosophical explanation of phenomena, either physical or moral; as Lavoisier's *theory* of combustion; Smith's *theory* of moral sentiments.'	Not present	Not present	OED 1989 records the denotative use of Theory A (Science) to 1638, 1706, 1727-41 and 1812.

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meanings**	**Keyword and semantic fields: The Penguin Roget's Thesaurus**	**Keyword and semantic fields: Macquarie Thesaurus**	**Comments**
	events or phenomena that have not yet been observed' (National Academy of Sciences, 2008).				
Darwinian theory	The theory, first developed by the 19th-century British naturalist Charles Darwin that species of living things originate, evolve and survive through natural selection in response to natural forces.	Webster's Dictionary 1898.	Not present	*Evolution* 225	
Theory B (Idea)	IDEA FORMED BY SPECULATION: An idea or belief about something arrived at through speculation or conjecture. HYPOTHETICAL CIRCUMSTANCES: a set of circumstances or principles that is hypothetical.	Webster's Dictionary 1828, corroboration OED 1989	*Supposition* 512n	*Notion* 497.1 *Credence/do-ubt/opinion* 152.2 *Conjecture* 131.2 *Subject Matter/ argument*720.2 *Subject Matter (hypothesis)* 131.2	OED 1989 defines Theory B as 'a mental view or contemplation'. Theory B is summed up as 'conjecture or opinion' (Wiktionary)
Theory C (Principles)	RULES AND TECHNIQUES: The body of rules, ideas, principles, and techniques that applies to a particular	Webster's Dictionary 1828, corroboration OED 1989	Not present	Not present	As an example, veterinary medicine combines theory (logos) and art (techne).

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus	Keyword and semantic fields: Macquarie Thesaurus	Comments
	subject, especially when seen as distinct from actual practice.				

Table 16. Dictionary meanings of words related to life and the living world that apply in the ontology for evolution theory.

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus
Adaptation [Adapt]	CHANGE TO SUIT ENVIRONMENT: The development of physical and behavioural characteristics that allow organisms to survive and reproduce in their habitats.	Webster's Dictionary 1828 and 1848 refers to adaptation as 'the act of making suitable, or the state of being suitable, or fit; fitness' and adapt as to make suitable; to fit or suit; as, to *adapt* an instrument to its uses; we have provision adapted to our wants. It is applied to things material or immaterial. OED 1888 refers to adaptation as 'the condition or state of being adapted (one thing fitted to another)' and quotes from *Origin of Species*. 'We see beautiful adaptations everywhere and in every part of the organic world'.	Adapt *Adjust* 24 *vb* *Modify* 143 *vb* *Translate* 520 *vb* Adaptation *Musical piece* 412n *Edition* 589n
Competition	TRYING TO BEAT OTHERS: the activity of doing something with the goal of outperforming others or of winning something. Competition: A trial to test the performance of something. Sheepdog trials test the skills of working animals. Ecology STRUGGLE FOR RESOURCES: the struggle between organisms of the same or different species for limited resources such as food or light.	The meaning of competition according to ecology was unavailable to Darwin. This definition is not apparent until OED 1989 and may be at odds with what Darwin intended. Darwin's use of the word competition may reflect events in the Agriculture Shows of his time, where items (plant products and animals) were compared and evaluated according to their perceived qualities.	
Descend [Descent]	*vti* BE RELATED to be connected by blood to an ancestor. *vi* BE INHERITED to be inherited from or passed down by parents or ancestors. ANCESTRAL BACKGROUND the connection sb has to an ancestor or group of ancestors. INHERITED	OED (1989) dates biological meaning to the 14th Century CE. To be derived by way of generation: to come of, spring from (an ancestor or ancestral stock). The fact of descending or being descended from an ancestor or ancestral stock, lineage.	Descend *land* 295 vb. *descend* 309 vb. Descent *consangui-nity* 11 n. *decrease* 37 n. *posteriority* 120

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus
	DEVELOPMENT characteristics or developments that can be traced to an earlier source.		n. *source* 156 n. *genealogy* 169 n. *sonship* 170 n. *descent* 309 n. *plunge* 313 n. *deteriorat-ion* 655 n.
Environment	NATURAL WORLD: The natural world within which people, animals and plants live. SURROUNDING INFLUENCES: All the external factors influencing the life of organisms such as light or food supply. SOCIAL AND PHYSICAL CONDITIONS: The conditions that surround people and affect the way they live.	Webster's Dictionary 1865, 'That which environs or surrounds' Webster's Dictionary 1898 'That which environs or surrounds; surrounding conditions, influences or forces by which living forms are influenced and modified in their growth and development.	*Circumstances* 8n *relation* 9n *location, locality* 187n *surroundings* 230n

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus
Fit (Fitness and fittest)	APPROPRIATE: Suitable, acceptable, or appropriate for a purpose. WORTHY: Worthy or deserving of something. WELL IN HEALTH: In good health. STRONG AND HEALTHY: Physically strong and healthy, especially because of taking regular exercise. APPEARING LIKELY TO DO SOMETHING: Appearing likely to do something because of being in an extreme condition.	Webster's Dictionary 1828, 1848. corroboration OED 1989. FIT Adjective: Suitable, convenient meet, becoming. Verb: To adapt, to suit, make suitable Worthy: One meaning from Webster's 1828: Qualified; as men of valor fit for war.	*Agreement, fit* 24 adj *Good policy, advisable* 642adj *health* 650adj *right* 913adj *Relation, relevance* 9n *Agreement, fitness* 24n *Preparation, preparedness* 669n *Skill, aptitude*

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meanings**	**Keyword and semantic fields: The Penguin Roget's Thesaurus**
		Worthy: Having social or moral value (Encarta) FITNESS Webster's Dictionary 1828, 1848. Noun: Suitableness, adaptedness, adaptation; as the fitness of things to their use.	694n
Habitat			
Hereditary [Heredity]	GENETICS, PASSED ON GENETICALLY passed genetically or capable of being passed genetically from one generation to another.	The definition of hereditary in genetics would not have been available to Darwin and Wallace. Late 18th Century meaning is transmissible from parent to offspring. This meaning is similar to that in *Mosby's Medical Dictionary, Ninth Edition* (O'Toole, 2013): transmitted from parent to offspring; inborn; inherited. Heredity is the process by which particular traits or conditions are genetically transmitted from parents to offspring, causing resemblance of individuals related by descent (O'Toole, 2013).	Hereditary *genetic* 5 adj. *filial* 170 adj. *proprietary* 777 adj. Heredity *heredity* 5 n.
Inherit [Inheritance]	RECEIVE A CHARACTERISTIC OR QUALITY FROM A PARENT to receive a characteristic or quality as a result of being passed on genetically. BIOL. TRANSMISSION OF GENETICALLY CONTROLLED CHARACTERISTICS the transmission of genetically controlled characteristics or	OED (1989) dates biological meaning to before the 19th Century. b. To derive (a quality or character (physical or mental) from one's progenitors by natural descent: to derive or possess by transmission from parents or ancestry. b. Natural derivation of qualities or	Inherit *Inherit* 771vb Inheritance *dower* 777n. *transfer* 771 adj.

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus
	qualities from parent to offspring,	characters from parents or ancestry- any property, quality or immaterial possession inheritedfrom ancestors or previous generations.	
Population	PEOPLE IN PLACE: All of the people who inhabit an area, region or country. ALL PEOPLE OF A GROUP: All of the people of a particular nationality, ethnic group, religion, or class who live in an area. NUMBER OF PEOPLE: The total number of people who inhabit an area, region, or country, or the number of people of a particular group who inhabit an area. SUPPLYING WITH INHABITANTS: The populating of an area with inhabitants. STATISTICS: GROUP STATISTICALLY SAMPLED: The entire group of individuals or items from which a sample may be selected for statistical measurement. *Ecology* INDIVIDUALS OF SAME SPECIES: All the plants or animals of a particular species in a place.	Meaning as STATISTICAL GROUP not found in Webster's Dictionaries from 1828 to 1930. OED presents population as 'a finite or infinite collection of items under consideration'.	*Inhabitants* 191n
Race	GROUP OR HUMANS: Any one of the groups into which the world's population [of people] can be divided on the basis of physical characteristics such as skin or hair colour. FACT OF BELONGING TO A GROUP: The fact of belonging to a group of humans who share the same physical features such as skin colour. HUMANKIND: Humanity considered as a whole. *Biology* STRAIN OF ORGANISM: A breed, strain, or sub-species of an organism.	Webster's Dictionary 1828, corroboration OED 1989.	*Consanguinuity: relations of kindred, race* 11n *Parentage, genealogy* 169n

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meanings**	**Keyword and semantic fields: The Penguin Roget's Thesaurus**
Replicate [Replication]	1. DO SOMETHING AGAIN to do something again or to copy something. 2. BE DONE AGAIN to undergo a repetition or reproduction. 3. BIOL. COPY CELLULAR OR GENETIC MATERIAL to reproduce exactly an organism, genetic material, or a cell. 2. BIOL MAKING OF CELLULAR OR GENETIC COPY the production of exact copies of molecules, genetic material or cells.	Webster's New World Dictionary(1986) 1. To fold; bend back. 2. to repeat or duplicate. (no reference to biology is given). OED (1989) dates biological meaning to 1957 and 1958 CE. d. Biology – Of genetic material or a living organism: to reproduce or give rise to a copy of (itself).	*Answer* 596.1, *copy* 144.2, *defence* 446.3, *duplication* 525.3, *echo* 636.2
Reproduce [Reproduction]	1. MAKE DUPLICATE OF SOMETHING. To duplicate something. or be duplicated by photographing, scanning, printing etc. 2. REPEAT SOMETHING to do something in the same way as before. 3. IN BIOLOGY. PRODUCE OFFSPRING to produce offspring or new individuals through a sexual or asexual process. 5. BIOL. PRODUCTION OF OFFSPRING the production of young plants and animals of the same kind through a sexual or asexual process.	OED (1989) dates biological meaning to at least 1611 CE and clearly to 1782 CE. 1.c. The process of producing new individuals of the same species by some form of generation: the generative production of new animal or vegetable organisms by or from existing ones; also, the power of reproducing in this way.	*Copy/copying* 144.2, *copy/copy* 525.1, *creation* 150.1, *duplication* 525.3, *procreation* 580.1, *proliferation* 335.1.

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meanings**	**Keyword and semantic fields: The Penguin Roget's Thesaurus**
Species	Biol TAXONOMIC GROUP: a subdivision of a genus considered as a basic biological classification and containing individuals that resemble one another and that may interbreed. Biol ORGANISMS IN SPECIES: the organisms belonging to a particular species. KIND OR SORT: a kind, sort of variety of something.	Webster's Dictionary 1828, corroboration OED 1989.	*77n breed*
Viable (viability)	1. PRACTICABLE OR WORTHWHILE able to be done or worth doing. 2 BIOl. ABLE TO GROW able to germinate or develop normally. 3. MED. ABLE TO SURVIVE OUTSIDE THE WOMB. This generally applies to a foetus after about 24 weeks of gestation. VIABILITY IS THE DERIVED NOUN	Not present in Websters Dictionary 1828 but appears in Websters Dictionary 1847 as 'capable of living'. OED (1989) refers to Websters Dictionary for date of appearance.	*360 alive* *469 possible*
Vital (vitality)	VITAL 1. CRUCIAL extremely important and necessary, or indispensable to the survival or continuing effectiveness of sth. 2. LIVELY full of animal or vigour. 3. OF LIFE relating to life. 4. NEEDED FOR LIFE required for the continuation of life. VITALITY 1. LIVELINESS abundant physical and mental energy usually combined with a whole-hearted and joyous approach to situations and activities. 2. DURABILITY the ability of sth to live and grow or	Present in Websters Dictionary 1828 as pertaining to life or contributing to life. OED (1989) records that vital as 'maintaining, supporting or sustaining life' dates at least to at least 1450.	*360 alive* *627 required* *638 important* *819 lively*

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meanings	Keyword and semantic fields: The Penguin Roget's Thesaurus
	continue in existence . 3. VITAL PRINCIPLE the nonmaterial force the, according to vitalism. Distinguishes the living from the nonliving.		

Table 17. Appendix Table A3: Figurative language used by Darwin in Origin of Species to substitute for contemporary biological terms (Word Category 3)

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meaning**	**Keyword and semantic fields: The Penguin Roget’s Thesaurus**	**Keyword and semantic fields: Macquarie Thesaurus**	**Comments**
Struggle	*Verb* TRY TO OVERCOME A PROBLEM: To try very hard to deal, with a challenge, problem, or difficulty. MAKE A GREAT PHYSICAL EFFORT: To make a great physical effort to achieve or obtain something. FIGHT BY WRESTLING. WRITHE TO ESCAPE. *Noun* GREAT EFFORT TO OVERCOME DIFFICULTIES: A great effort made over a period of time to overcome difficulties and achieve something. HARD TASK: A strenuous physical effort, or something requiring this. FIGHT.	Webster’s Dictionary 1828, corroboration OED 1989.	*Intention, contest* 617n *[Found in Section 2: Prospective volition]*	*Contest* 139.1 *Attempt. Striving* 44.1 *Easiness/Difficulty. Task* 193.2	‘Struggle’ in all its do not reflect the ac according to Natur
Struggle for existence	*Noun*. The ongoing effort to survive and reproduce in an environment of competing organisms. ‘Struggle for existence’ occurs in OED 2 (1929) ‘to describe the relation	‘Struggle for existence’ does not occur as a phrase in Webster’s dictionaries from 1828 to 1930.	Not present	Not present	The phrase ‘strugg and is incompatible processes. Compar

Word	**Relevant meanings: Encarta Dictionary of World English**	**Credible date of common use of relevant meaning**	**Keyword and semantic fields: The Penguin Roget’s Thesaurus**	**Keyword and semantic fields: Macquarie Thesaurus**	**Comments**

Word	Relevant meanings: Encarta Dictionary of World English	Credible date of common use of relevant meaning	Keyword and semantic fields: The Penguin Roget's Thesaurus	Keyword and semantic fields: Macquarie Thesaurus	Comments
	between coexisting organic species when the causes tending to the survival of one tend to the extinction of another'				

Appendix 3. Review of Terms Similar to or Related to ‘Ontology’ and ‘Conceptual Framework’.

The knowledge representation entity known as an ontology which classifies as ‘conceptual framework’ was selected to construct the user-interface between theory of evolution by natural selection and One Health because of its potential benefits for sound communication, universal intelligibility and universal access to knowledge. Conceptual frameworks as a class seek to provide a reliable and concise overview of a subject that allows for practical application. Conceptual frameworks are not fixed and are open to modification in the light of advancing knowledge. In particular, conceptual frameworks facilitate causal reasoning and the diagnostic processes applying in every compartment of One Health. Causal reasoning entails inferences according to pathophysiology and looks to cause-and-effect relations that can be arrived at by analysis of structure and function in health and disease (Kassirer et al., 2009). Causal reasoning evaluates phenomena observed in ecosystems, communities, populations, whole organisms and those observed at the organ, tissue, cell and sub-cellular levels of biological organisation. Causal reasoning is central to the usual diagnostic processes employed in veterinary medicine (Radostits, Tyler and Mayhew, 2000) and elsewhere. Ontologies are more explicit and are employed to optimise the accurate exchange and use of information within computer networks.

A rationale for the choice of an ontology or variant of a ‘conceptual framework’ to fashion the user-interface between theory of evolution by natural selection and the One Health is set out by Figure 11 and Box 13. Figure 11 is a concept map showing linkages between conceptual frameworks and related terms and ideas in everyday use, in general use across the whole of science and with special use in computer science. Box 13 sets out definitions of conceptual framework and other terms shown in Figure 11. The definitions displayed detail the form and function of each knowledge representation entity. In short, conceptual frameworks are the only knowledge representation entity that provides a focus, rationale, and instrument for the integration, interpretation and application of knowledge and a pathway towards new knowledge. Conceptual frameworks provide a tool for exploration and reasoning within a topic area. By contrast, scientific models provide a tool for exploration and demonstration within a topic area. Conceptual frameworks and scientific models complement one another beneficially. Conceptual frameworks provide descriptions for the factors or sorts of things that are quantified within scientific models. Trial-and-error experience with scientific models can result in improvements to conceptual frameworks.

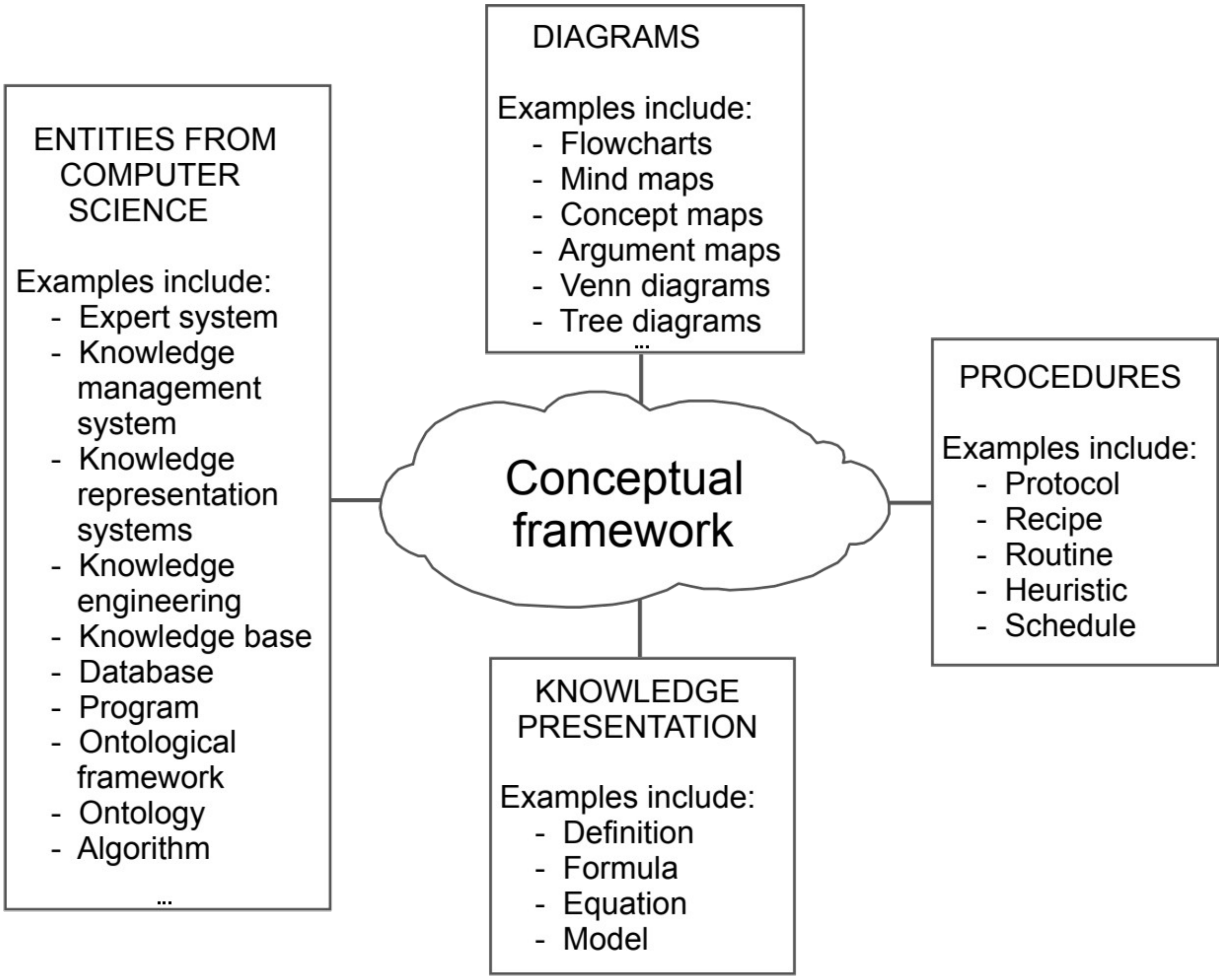

Figure 11: A concept map that orients the term, conceptual framework, within a web of related terms in everyday use and in the speciality of computer science which specifies ontologies

[Note: Fuzzy logic which is a method of convenience used in computing is excluded. Fuzzy logic employs ‘degrees of truth’, as opposed to the logically consistent ‘true or false’.]

Box 13: Definitions of the term ‘conceptual framework’ and associated terms in every day use, in general use in science and use in the speciality of computer science.

1. Conceptual framework
A grouping or assemblage of concepts that are appropriately defined and systematically organised [FORM] to provide a focus, rationale, and instrument for the integration, interpretation and application of knowledge and a pathway towards new knowledge [FUNCTION]. Conceptual models are open to modification as knowledge advances.

2. Terms associated with ‘conceptual framework and in everyday use or general use in science

Group 1 - Procedures

Heuristic
An intelligent trial-and-error approach, as opposed to a rigid algorithmic method [FORM]. Heuristics are used in computer programs which can learn from experience in fields such as machine learning and artificial intelligence, and

their non-rigorous nature is also suited to expert systems [FUNCTION](Clugston, 2014).

Protocol
A protocol within computing or communication refers to the combination of rules and guidelines that govern how data is transmitted and received between devices or systems [FORM]. Protocols set out the format, timing, sequencing, and measures for managing errors that make for successful communication [FUNCTION].
The detailed plan of a scientific experiment, medical trial or other piece of research (Rooney, 1999).

Recipe
List of ingredients and instructions [FORM] for making something, especially for (but not restricted to) a food dish [FUNCTION]. A method for doing something or a combination of circumstances likely to bring something about (Rooney, 1999).

Routine
A customary procedure or regular course [FORM] for undertaking a task or activity [FUNCTION].

Group 2 – Diagrams

Diagram
Diagrams are visual presentations of information that help clarify, simplify and illustrate complex ideas (Braigrie, 1996; Eddy, 2020). They include flowcharts, graphs, Venn diagrams, concept maps, block diagrams and conceptual frameworks that work by showing how different elements in a matter of interest mesh. In doing so, diagrams and the related idea of a schema make complex relationships more intelligible. Diagrams and written texts complement one another to make communication more effective.

Concept map
A concept map is a diagram [FORM] that shows how ideas around a particular topic relate to one another [FUNCTION]. Concept maps are pictorial way organising and representing knowledge [FUNCTION].

Concept schema
A schema is a diagram or plan [FORM] showing the outline of something like a set of interrelated concepts [FUNCTION] .

Mind map
Mind maps are enigmatic and have been publicised but not been explained by expository and disinterested discourse (Buzan, 2006 and 2024) A mind maps may be equivalent to a concept map or a concept schema.

Model
In science, a physical, conceptual, or mathematical representation of a real phenomenon that is difficult to observe directly [FORM]. Scientific models are used to explain and predict the behaviour of real objects or systems and are used in a variety of scientific disciplines, ranging from physics and chemistry to ecology and the Earth sciences [FUNCTION]. Scientific models at best are approximations of the objects and systems that they represent—they are not exact replicas.

Group 3 – Knowledge representation

Definition
An exact statement or description [FORM] of the nature, scope and meaning of something [FUNCTION].

Equation
In chemistry, a representation of a chemical reaction [FUNCTION] using the symbols of the elements to represent the actual atoms or molecules taking part in the reaction [FORM] (Uvarov and Chapman, 1951).
In mathematics, a statement of equality between known and unknown quantities true only for certain values of unknown quantities [FORM] (Uvarov and Chapman, 1951). Equations convert unknown quantities into known quantities [FUNCTION].

Formula

In chemistry, the representation of a molecule or smallest portion of a compound, using symbols for the atoms of the elements that make up the compound [FORM and FUNCTION] (Uvarov and Chapman, 1951).
In mathematics and physics, a statement of facts in a symbolical or general form (FORM], by substitution in which a result applicable to a particular data may be obtained [FUNCTION] (Uvarov and Chapman, 1951).

3. Terms associated with 'conceptual framework' and used in the speciality of computer science

Algorithm
A formal sequence of instructions, given in unambiguous and logical language [FORM], that may be followed in order to achieve a particular purpose, such as sorting a set of numbers in a computer's memory [FUNCTION] (Clugston, 2014).

Ontology
An ontology is a formal representation of knowledge that describes the entities, concepts, and relationships within a specific domain [FORM]. It aims to provide a structured and detailed representation of the domain's vocabulary and the semantics of its concepts[FUNCTION]. Ontologies are used in knowledge engineering, information systems, artificial intelligence, and the Semantic Web to enable machine-readable and interoperable knowledge representation [FUNCTION].

Ontological framework
Ontological frameworks provide a structured approach and guidelines for developing, organising, and managing ontologies as formal representations of knowledge [FORM]. Ontological frameworks facilitate consistency and interoperability in representing knowledge and reasoning about knowledge within specific domains or across different domains [FUNCTION]. A domain is a specific area or context.

Program
A program is a concrete implementation of an algorithm using a programming language. It is a collection of instructions written in a specific programming language that can be executed by a computer [FORM]. A program translates the algorithmic steps into a form that a computer can understand and execute [FUNCTION].

Knowledge base
A knowledge base is a repository or collection of organized knowledge [FORM] that is typically used to store and manage information, facts, rules, and other forms of knowledge[FUNCTION].

Knowledge representation system
A knowledge representation system is a software tool or framework [FORM] that enables the representation, organisation, and reasoning about knowledge using formal models or representations [FUNCTION].

Knowledge management system
A knowledge management system (KMS) is a software application or platform [FORM] that facilitates the creation, organisation, storage, retrieval, and dissemination of knowledge within an organisation or domain [FUNCTION].

Expert system
An expert system is a software application that uses knowledge and inference rules to emulate the decision-making ability of a human expert in a specific domain [FORM] and thus to provide intelligent solutions or advice [FUNCTION].

Appendix 4. Causal Inference and Causation in One Health

Causal reasoning is the foundation of diagnosis in One Health and was alluded to in section 4.3.6a which considered how Koch's postulates stimulated advances in the understanding of causality and causation. Progress in the general area of disease causation is exemplified by the Hill's criteria. These are nine principles to guide the collection of evidence for a causal relationship between a

putative cause and an observed effect (Hill, 1965). Progress in the area of infectious disease causation is exemplified by Evans' rules (Evans, 1974). Progress in the area of causation and causal inference across the whole One Health is exemplified by the conceptual framework provided by causal pies, sufficient cause and component causes (Rothman, 1976; Laake et al., 2004; Rothman and Greenland, 2005; Rothman et al., 2008; Thrusfield and Christley, 2018). Hill's criteria and Evans' rules are shown below.

Hill's Criteria for Causation

The following background to the nine principles know as the Hill's criteria for causation comes from Hill (1965):

> 'Disregarding then any such problem in semantics we have this situation. Our observations reveal an association between two variables, perfectly clear-cut and beyond what we would care to attribute to the play of chance. What aspects of that association should we especially consider before deciding that the most likely interpretation of it is causation?'

The nine principles making up Hill's criteria for causation are:

1. Strength (effect size): A small association does not mean that there is not a causal effect, though the larger the association, the more likely that it is causal.
2. Consistency (reproducibility): Consistent findings observed by different persons in different places with different samples strengthens the likelihood of an effect.
3. Specificity: Causation is likely if there is a very specific population at a specific site and disease with no other likely explanation. The more specific an association between a factor and an effect is, the bigger the probability of a causal relationship.
4. Temporality: The effect has to occur after the cause (and if there is an expected delay between the cause and expected effect, then the effect must occur after that delay).
5. Biological gradient (dose–response relationship): Greater exposure should generally lead to greater incidence of the effect. However, in some cases, the mere presence of the factor can trigger the effect. In other cases, an inverse proportion is observed: greater exposure leads to lower incidence.
6. Plausibility: A plausible mechanism between cause and effect is helpful (Hill noted that knowledge of the mechanism is limited by current knowledge).
7. Coherence: Coherence between epidemiological and laboratory findings increases the likelihood of an effect. Hill noted that 'lack of such [laboratory] evidence cannot nullify the epidemiological effect on associations'.
8. Experiment: 'Occasionally it is possible to appeal to experimental evidence'.
9. Analogy: The use of analogies or similarities between the observed association and any other associations.

Evan’s Rules: A Unified Concept for Causation

The following list of criteria for causation repeats Table 13 in Evans (1976).

Criteria for Causation: A Unified Concept

1. Prevalence of the disease should be significantly higher in those exposed to the putative cause than in cases controls not so exposed. [The putative cause may exist in the external environment or in a defect in host response.]
2. Exposure to the putative cause should be present more commonly in those with the disease than in controls without the disease when all risk factors are held constant.
3. Incidence of the disease should be significantly higher in those exposed to the putative cause than in those not so exposed as shown in prospective studies.
4. Temporally, the disease should follow exposure to the putative agent with a distribution of incubation periods on a bell shaped curve.
5. A spectrum of host responses should follow exposure to the putative agent along a logical biologic gradient from mild to severe.
6. A measurable host response following exposure to the putative cause should regularly appear in those lacking this before exposure (i.e., antibody, cancer cells) or should increase in magnitude if present before exposure; this pattern should not occur in persons so exposed.
7. Experimental reproduction of the disease should occur in higher incidence in animals or man appropriately exposed to the putative cause than in those not so exposed; this exposure may be deliberate in volunteers, experimentally induced in the laboratory, or demonstrated in a controlled regulation of natural exposure.
8. Elimination or modification of the putative cause or of the vector carrying it should decrease the incidence of the disease (control of polluted water or smoke or removal of the specific agent).
9. Prevention or modification of the host's response on exposure to the putative cause should decrease or eliminate the disease (immunization, drug to lower cholesterol, specific lymphocyte transfer factor in cancer).
10. The whole thing should make biologic and epidemiologic sense.

Glossary

Adaptation
(see also maladaptation)
Any peculiarity, property or feature of the structure, physiology or behaviour of an organism or biological entity, such as a virus or prion, that enables it to survive and reproduce in a particular environment. Adaptations can be depicted as the capabilities that underpin viability and reproduction (precising definition explained in section 3.4.5).

Aetiology
1. a. The study of causes or origins. b. The branch of medicine that deals with the causes or origins of disease.
2. a. Assignment of a cause, an origin, or a reason for something. b. The cause or origin of a disease or disorder as determined by medical diagnosis. (American Heritage Dictionary of the English Language, https://www.ahdictionary.com/).

Agency
1. Agency in general biology refers to the capacity of organisms, sub-organisms (viruses and or systems of organisms to act autonomously and exert control over actions and to select actions according to information inputs (see Section 4.2.3)(precising definition). Agency overlaps with the concept of autopoiesis.
2. Agency for purposes of the ontology and its concept hierarchy refers to that by which something [such as evolution] is done or achieved (Webster's) and according to the organisation and nature of component causes that constitute Subordinate Concept 3. Agency is inspired by the substance of a theory.

Agrifood System
The entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries, as well as food industries and the broader economic, societal and natural environments in which they are embedded (FAO, UNEP, WHO, and WOAH. 2022).

Agroecology
(see also regenerative agriculture, sustainable agriculture)
1. By way of ecology, the scientific basis for agriculture, forestry, and agroforestry (Wojtkowski, 2019).
2. The scientific basis for the cultivation of food, fuel, fiber, and other land-raised products with deference to and/or in cooperation with nature and natural processes (Wojtkowski, 2019).

AGROVOC
Since the early 1980s, FAO has coordinated AGROVOC, a valuable tool for data to be classified homogeneously, facilitating interoperability and reuse. AGROVOC is a multilingual and controlled

vocabulary designed to cover concepts and terminology under FAO's areas of interest. It is a relevant Linked Open Data set about agriculture, available for public use, and its highest impact is through facilitating the access and visibility of data across domains and languages (fao.org/agrovoc).

AIMS
The Agricultural Information Management Standards Portal (AIMS) of the Food and Agricultural Organization of the United Nations (FAO) gathers information on (and access to) standards, technology and best practices. It is also a forum connecting information management workers around the world to discuss open access and open data (https://aims.fao.org/node/4236).

Algorithm
A formal sequence of instructions, given in unambiguous, explicit and logical language [FORM], that may be followed in order to achieve a particular purpose, such as sorting a set of numbers in a computer's memory [FUNCTION] (Clugston, 2014).

Allee effect
Phenomenon where individuals in a population have lower fitness (reduced survival or reproduction) at low population densities due to difficulties in finding mates and other cooperators and reduced group defences against predators.

Allele (allelomorph)
(1) One of several alternative forms of a gene at a given gene locus (Passarge, 2007).
(2) Refers to either of the two alternative forms of a gene occupying the same site (locus) in genomes of life forms that reproduce sexually (precising definition).

Allelopathy
The chemical inhibition of one plant (or other organism) by another, due to the release into the environment of substances acting as germination or growth inhibitors (Apple Dictionary 2.2.2).

Allostasis
Allostasis is complementary to homeostasis and emphasises the dynamic behavioural and physiological mechanisms that are used to anticipate or cope with environmental change to maintain organismal function (Schulte, 2014).

Allostatic load
The wear and tear on the body which accumulates when an individual is repeatedly exposed to stressors (McEwen and Stellar, 1993).

Altruism
Any act or behaviour which results in an individual increasing the genetic fitness of another at the expense of its own, e.g. by devoting large amounts of time and resources to caring for another individual's offspring at the expense of producing its own (Lawrence, 2008).

Amensalism
An association between organisms where one population is inhibited and the other population is unaffected (Odum, 1983).

Animate versus inanimate entities
Capabilities for agency and the management, representation and processing of information distinguish animate from inanimate entities (precising definition).

Antibioisis
Antibiosis refers to antagonistic associations among organisms in which one produces compounds, known as antibiotics, which are harmful to the other(s) (Lawrence, 2008). Antibiotics are pre-eminent in the treatment of bacterial infections in humans and animals (Aminov, 2010).

Antibiotic Resistance (see antimicrobial resistance, AMR)

Antibiotics (see antimicrobials)

Antigenic drift
The appearance of a virus with slightly changed antigenicity after frequent passage in the natural host. This is presumably due to selection of mutants under pressure of the immune response. Commonly described in influenza virus infections, but also observed with many other viruses. Synonym: immunological drift (Mahy, 2009)

Antigenic shift
1. A major change in one or more surface proteins of a virus when genes encoding markedly different surface proteins are acquired during infection; this process occurs when viruses with segmented genomes exchange segments, or when non-segmented viral genomes recombine after coinfection (Flint et al., 2015).
2. A sudden and major change in the antigenicity of a virus resulting from genetic recombination (gene reassortment). Most likely to occur in viruses with segmented genomes, but only reported in influenza virus A to date. Occurred in 1957 when Asian influenza appeared, and again in 1968 when Hong Kong influenza appeared (Mahy, 2009).

Antimicrobial resistance (AMR)
Antimicrobial Resistance (AMR) occurs when bacteria, viruses, fungi and parasites no longer respond to antimicrobial agents. As a result of drug resistance, antibiotics and other antimicrobial agents become ineffective and infections become difficult or impossible to treat, increasing the risk of disease spread, severe illness and death (FAO, UNEP, WHO, and WOAH. 2022).

Arms race
See coevolutionary arms race.

Artificial intelligence

See also machine learning

1. Negnevitsky (2011): The field of computer science concerned with developing machines that behave in a way that would be considered intelligent if observed in humans.
2. Kaplan and Haenlein (2019): A system's ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation.
3. ChatGPT (with modifications): The broad field of creating machines or computer systems that can perform tasks that otherwise require human intelligence. Artificial intelligence amalgamates various techniques and capabilities like machine learning, natural language processing, computer vision, robotics, reasoning, problem-solving, perception, knowledge representation, planning, decision-making, and adaptability. These capabilities combine to mimic human intelligence and behaviour.

Artificial selection

Refers to the selection of plants, animals, fungi and other organisms made by humans according to observations and perceptions of structure, behaviour and performance in diverse environments. As for natural selection, artificial selection acts through the phenotypes of individual organisms to affect the frequency of genotypes in succeeding generations or populations (precising definition).

Autopoiesis

Term coined by Maturana and Varela (1972). Autopoiesis refers to the self-producing, self-maintaining, self-repairing and self-relational aspects of living systems. Autopoiesis combines the Greek prefix 'auto' meaning self and the Greek prefix 'poiesis' meaning fabrication, creation, production and which derives from the Greek word meaning to make (see Liddell and Scott, 1968). Margulis and Sagan (1995) updated the term and gave it cogency by reference to thermodynamics and information. Autopoiesis overlaps with the concept of agency.

Bacteriocin

Bacteriocins are a group of proteins secreted by bacteria that kill or inhibit competing strains (Day, 1998) and which are used in food preservation Cleveland, 2001).

Balancing selection

The type of selection that favors more than one allele. This process acts to maintain genetic diversity in a population by keeping alleles at frequencies higher than would be expected by chance or mutation alone (precising definition).

Biodiversity

The variability of living organisms from any source, including, among other things, terrestrial ecosystems and marine and other aquatic ecosystems and the ecological complexes of which they are part; it includes diversity within species, between species and of ecosystems (One Health Joint

Plan of Action).

Biology
The science dealing with living organisms [and life forms such as prions and viruses], a term coined by J.B. de Lamarck in 1802. Biology includes all the life science such as anatomy, physiology, cytology, botany, zoology, microbiology, ecology, ethology, genetics, biophysics and biochemistry (adapted from Lafferty and Rowe, 1995; Lawrence, 2008).

Biometry
Literally, the measurement of living things but generally means the application of mathematics to biology. The term is now largely obsolete, since mathematical or statistical work is an integral part of most biological disciplines. Biometry is unsafe unless variables in question have a clear definition in biology.

Biont
A discrete unit of living matter and a term that covers cellular organisms and subcellular life forms (viruses, viroids, virusoids and prions). Term 'biont' derives from the Greek word 'bios', means life. Additions of prefixes can denote key specific aspects of discrete units of living matter or organisms. For instance, symbionts live within other organisms and halobionts are organisms that live in salty environments (precising definition).

Biosecurity
Biosecurity is a strategic and integrated concept that encompasses the policy and regulatory frameworks (including instruments and activities) that analyse and manage risk in food safety, public health, animal life and health, and plant life and health, including associated environmental risk (FAO, 2007b; Renault et al., 2022)

Biosensitive society
A society that is based on understanding the human place in nature and in which human society is sensitive to, in tune with, and respectful of the processes of life (Boyden, 2016).

Bottleneck
Population or genetic bottlenecks are acute and substantial reductions in the size of populations and their diversity resulting from catastrophic environmental events like disease, famine, earthquakes, floods, fires, drought and harmful human activities (precising definition).

Bridging host
(see host)

Capability (Ability, Capacity):
Ability: Being able, power to do (Webster's Collegiate Dictionary). The power or capacity to do or act in any relation (Macquarie). Being able; power to do (Collins). Sufficient power, capacity to do something (Concise Oxford).
Capability: The quality of being capable or having ability (Webster's). The quality of being capable, capacity, ability (Macquarie). The quality of being capable; practical ability (Collins). Power of action (Concise).

Capacity: The quality of of being adapted (*for* something) or susceptible (*of* something)(Webster's).

Capsid

External protein coat of a virus particle (precising definition).

Causation unit

The organisation of component causes (namely; processes, capabilities, adaptations, structures, functions and mechanisms) that allow for agency or the way something is done or achieved (precising definition).

Cell

1. The basic structural building block of living organisms, consisting of protoplasm delimited by a cell membrane (Lawrence, 2008).
2. The basic structural building block of living organisms, consisting of protoplasm delimited by a cell membrane that produces an open thermodynamic unit able to regulate the exchange of matter and energy with the surrounding environment.

Cell Theory

1. The crux of cell theory in the life sciences is that the cell is the fundamental unit of life.
2. Cellular organisms as life forms are composed of one or more cells.
3. All cells come from other cells.
4. Cells and their order and organisation are the ultimate vehicle for all life forms which can be either sub-cellular, unicellular or multicellular.
5. Cells possess membranes that regulate exchanges of matter and energy with the surrounding environment and their operation as open thermodynamic units.
6. Cells are the basic unit of function and organisation of all life forms.
7. Cells provide the machinery manipulated by sub-cellular life forms exemplified by viruses and prions to express the properties of life: based on Tobin and Morel (1997) and modified according to 4.3.1 on organisation as a fundamental concept in biology.

Cistron

A segment of DNA that contains all the information necessary for the production of a single polypeptide and includes both the structural (coding) sequences and regulatory sequences (precising definition).

Climate change
(see also global warming and greenhouse effect)

- Climate change refers to long-term shifts in temperatures and weather patterns. Such shifts can be natural, due to changes in the sun's activity or large volcanic eruptions. But since the 1800s, human activities have been the main driver of climate change, primarily due to the burning of fossil fuels like coal, oil and gas. Burning fossil fuels generates greenhouse gas emissions that act like a blanket wrapped around the Earth, trapping the sun's heat and raising temperatures.

- The main greenhouse gases that are causing climate change include carbon dioxide and methane. These come from using gasoline for driving a car or coal for heating a building, for example. Clearing land and cutting down forests can also release carbon dioxide. Agriculture, oil and gas operations are major sources of methane emissions. Energy, industry, transport, buildings, agriculture and land use are among the main sectors causing greenhouse gases (https://www.un.org/en/climatechange/what-is-climate-change).

Climate change denialism (denial)
Climate change denial (also global warming denial) is a form of science denial characterized by rejecting, refusing to acknowledge, disputing, or fighting the scientific consensus on climate change. Those promoting denial commonly use rhetorical tactics to give the appearance of a scientific controversy where there is none. Climate change denial includes unreasonable doubts about the extent to which climate change is caused by humans, its effects on nature and human society, and the potential of adaptation to global warming by human actions. To a lesser extent, climate change denial can also be implicit when people accept the science but fail to reconcile it with their belief or action. Several studies have analyzed these positions as forms of denialism. Pseudoscience or propaganda.

Cline

Graded series of different forms of the same species, usually distributed along a spatial dimension and representing phenotypic plasticity (based on Lawrence, 2008).

Coevolution
(see also Evolution)
1. Reciprocal evolutionary change among interacting species driven by natural selection (Thompson, 2014).
2. The process in which evolutionary change of one species influences the evolution of another species (Boughman, 2014).
3. Reciprocal evolutionary change between interacting species (Cavanaugh and Currie, 2014).

Coevolutionary arms race
The sequence of mutual counter-adaptations of two co-evolving species such as a parasite and its host (Turner, 2014).

Commensalism
An interaction between species in which one population is benefited, but the other is not affected (Odum, 1983).
Association between two organisms of different species that live together and share food resources, one species benefiting from the association and the other not being harmed (Lawrence, 2008).

Communicable disease

(See also contagion, infection, infectious, infectious disease and transmissible disease)
Infectious disease transmitted from person to person or animal to animal by direct contact with excreta or other discharges from the body, indirect contact with the disease agent in water or air substances or on inanimate objects (fomites) or by means of vectors, such as flies, mosquitoes, ticks, or other insects. Communicable diseases may be caused by prions, viruses, bacteria (monerans), protozoa (protistans), fungi and metazoan endoparasites and ectoparasites (precising definition).

Communication

1. The exchange of information between individuals, e.g. by means of speaking, writing or using a common system of signs or behaviour (Rooney, 1999).
2. Communication in biology refers to the signalling of information from one organism to another, usually with the intention of altering the recipient’s behaviour. Signals used in communication may be visual (such as the human smile or the display of colourful plumage in birds), auditory (for example, the whines and barking of a dog), olfactory (such as the odours released by the scent glands of a deer), electrical (such as the pulses emitted by electric fish) or tactile (such as the nuzzling of male and female elephants)(Lafferty and Rowe, 1995).
3. Process by which one animal provides information that other animals can incorporate into their decision making. The vehicle for the provision of this information is called a signal. The signal may be a sound, colour pattern, posture, movement, electrical discharge, touch, release of an odorant, or some combination of these mediums (https://www.britannica.com/science/animal-communication).
4. Animal communication involves the use of signals to convey information between animals, which can influence the behaviour of the receiver. These signals can take various forms, including sounds, visual displays, chemical signals, and tactile interactions. Unlike human language, animal communication does not typically involve the complex syntax and grammar that characterise human languages. Instead, animal signals are often specific to particular contexts, such as mating, territory defence, or alerting others to danger. Communication does not necessitate language (https://www.britannica.com/science/animal-communication).

Competition

1. Definition from ecology
Direct inhibition type: An interaction between species in one population actively inhibits the other. See allelopathy, antibiosis, bacteriocin.
Resource use type: An interaction between species in which each population adversely affects the other indirectly in the struggle for resources in short supply (Odum, 1983).
2. Definition from evolutionary biology: An interaction between individuals of the same species or different species whereby resources used by one are made unavailable to others (Futuyma and Kirkpatrick, 2017).

Concept hierarchy

(precising definition)

1. A concept is an idea or mental image which corresponds to some distinct entity or class of entities, or to its essential features, or determines the application of a term (especially a predicate), and thus plays a part in the use of reason or language (https://dictionary.apa.org/concept).
2. Concepts can be arranged or ranked as hierarchies. Concepts at higher levels cover a broader scope than those at lower levels and are called superordinate concepts. Taxonomies in biology epitomise concept hierarchies and refer to classifications or groupings in which entities (that is types of organisms) are graded into groups or types ranging downwards from kingdoms to phyla and so on.
3. Subordinate concepts falls below superordinate concept and cover a narrower scope. In biological classifications a species is subordinate to a genus, a genus is subordinate a family, a family is subordinate to an order and so on.
4. Superordinate concepts rank above subordinate concepts and cover a broader scope. In biological classifications, a phylum ranks higher than a class, and a class ranks higher than an order. Successively higher superordinate categories cover progressively broader scopes. Concept categories are crucial for organising the ontologies used in artificial intelligence, knowledge engineering and machine learning..

Concept map
A concept map is a diagram [FORM] that shows how ideas around a particular topic relate to one another [FUNCTION]. Concept maps are pictorial way organising and representing knowledge [FUNCTION] (precising definition).

Concept schema
A schema is a diagram or plan [FORM] showing the outline of something like a set of interrelated concepts [FUNCTION] (precising definition).

Conceptual framework
A grouping or assemblage of concepts that are appropriately defined and systematically organised to provide a focus, rationale, and instrument for the integration, interpretation and application of knowledge and a pathway towards new knowledge. Conceptual models are open to modification as knowledge advances (precising definition).

Connotation
1. A meaning of a word or phrase that is suggested or implied, as opposed to a denotation, or literal meaning.
2. An implied additional meaning; an additional sense or senses associated with or suggested by a word or phrase (Rooney, 1999).

Contagion
1. The process by which a disease is passed from one person or animal to another by direct or indirect contact or by way of an intermediary.
2. A disease entity that spreads by means of the process of contagion.

3. The term contagion presaged the germ theory and is attributable to Girolamo Fracastoro (1476-1553) who proposed that syphilis was spread by ‘seeds’ distributed by intimate contact (Lederberg, 2000).

Convergent evolution
The independent appearance of similar features or traits in separate evolutionary lineages and populations (precising definition).

Critical thinking
A process, the goal of which is to make reasonable decisions about what to believe and what to do. (Ennis RH, 1996, *Critical Thinking*. Prentice-Hall, Upper Saddle River, New Jersey; Quoted by Damer, 2005).

Dead-end host
(see host)

Death
Denotes the end of life, or the end of existence, of an organism (biont) and refers to the cessation of processes that sustain life as an open thermodynamic system the termination of the chemical and. physical mechanisms that allow for responsiveness, growth, metabolism, energy transformation, self-maintenance (homeostasis and allostasis) and replication/reproduction. Viruses and prions (semibionts), which do not themselves act as open thermodynamic systems, cease to exist or are destroyed when the macromolecules that mediate their functions and allow for viability are disassociated or disintegrated, or both (precising definition).

Definition
1. ‘A definition seeks to ascertain and encapsulate the characteristics and nature of a thing and so identify and explain what a thing is’ (modified from Barnhart and Barnhart, 1979; World Book Dictionary).
2. An exact statement or description [FORM] of the nature, scope and meaning of something [FUNCTION] (precising definition).
3. Definitions can be lexical, precising, theoretical or persuasive (Hurley, 2003). Precising definitions have the purpose for reducing the vagueness of a term and are mandated for the ontologies used in computer technology.

Definitive host
(see host)

Denotation
1. The literal or primary meaning of a word, in contrast to the feelings or ideas that the word suggests.
2. Basic meaning: the most specific or literal meaning of a word (Rooney, 1999).

Diagnosis

The process of determining the health status and the factors responsible for it; may be applied to an individual, family, group, society [plant, animal, plant population, animal population, plant community, animal community, ecosystem]. The term is applied both to the process of determination and to its findings (adapted from Porta, 2014).

Diction

1. The choice and use of words and phrases in speech or writing especially in regard to effective communication.
2. Choice of words to fit their context (Rooney, 1999).

Discourse, forms of
(from Vivian and Jackson, 1961)

Exposition as a form of discourse aims to explain, inform, or describe a subject, presenting facts, definitions, or explanations to enhance the audience's understanding.
Argument as a form of discourse seeks to persuade or convince the audience by presenting claims supported by evidence and reasoning, aiming to influence beliefs or actions.
Description as a form of discourse focuses on creating a vivid image or sensory experience for the audience by detailing the qualities, characteristics, or appearance of a person, place, thing, or event.
Narration as a form of discourse tells a story or recounts events in a sequence, often with a focus on characters, setting, and plot, to convey an experience or illustrate a point.

Disease

1. The failure of the adaptive mechanisms of an organism to counteract adequately the stimuli or stresses to which it is subject, resulting in a disturbance in function or structure of any part, organ or system of the body. The cause of a disease entity is represented by the cause of the basic pathological process in combination with secondary causative factors (Hoerr and Osol, 1956).
2. A manifestation of disordered function that can afflict all life forms and which operates in a gradient from health and vigour to poor health and disease (Ganong, 2006).
3, Failure of the adaptive mechanisms of a life form (the disease-bearer) to respond effectively to imposed stimuli or stresses that results in disturbed function or structure at any level of organisation and impaired integrity and which occurs as a gradient from vigour and health to poor health and disease. A given disease is caused by the agent responsible for the basic pathological process plus secondary causative factors that allow for disease susceptibility and severity[106] (precising definition).

Divergent evolution (divergence)

The evolution of increasing differences between lineages in one or more characters (Futuyma and Kirkpatrick, 2017).

Ecological niche

[106]These factors list as (1) predisposing factors that increase the level of susceptibility in the disease-bearer, (2) enabling factors that facilitate the manifestation of disease (for example poor housing and nutrition of farm animals) and (3) reinforcing factors that aggravate the presence of a given disease (Thrusfield, 1986).

(see also ‘habitat’ and ‘food chain’)
Term for the position of a species within an ecosystem and which refers to the range of conditions necessary for the persistence of a species and its ecological activities in an ecosystem. Ecological niches entail all interactions between a species and the abiotic or physical environment and the biotic environment which refers to associations among species that range from predation to cooperative mutualism and the trophic level occupied by a given species in the food chain and food webs. Two-way interactions mean that the environment can affect a species and a species can affect its environment and thus affect other species.

Ecosystem
Community of different species interdependent on each other, together with their non-living environment, which is relatively self-contained in terms of energy flow, and is distinct from neighbouring communities. Different types of ecosystem are defined by the collection of organisms found within them, e.g. forest, soil, grassland. Continuous ecosystems covering very large areas, such as the northern coniferous forest or the steppe grassland, are known as biomes (Lawrence, 2008).

Ecosystem health
The extent to which an ecosystem (or group of ecosystems) is able to function, maintain ecological and evolutionary processes, adapt to change and cope with the impacts of human activity (FAO, UNEP, WHO, and WOAH. 2022).

Emergence
Emergence refers to the appearance of new characteristics, or emergent properties, at successive levels of organisation from molecules to whole organisms

Emergent properties
Emergent properties reflect the general principle that form follows function and are generated by interactions among the organised component parts of living systems. Emergent properties at successive levels in the hierarchy of organisation from cells and their molecular machinery, through, tissues, organs, organisms to biotic communities build one upon another to create new and complex more emergent properties such as consciousness in animals (precising definition).

Emerging infectious disease (EID)
A disease that has either has appeared and affected a population for the first time, or has existed previously, but is rapidly spreading, either in terms of the number of individuals getting infected, or to new geographical areas (FAO, UNEP, WHO, and WOAH. 2022).

Endemic infectious disease
An infectious disease that occurs frequently in a specific population or geographical area, often in cycles, and may remain there indefinitely (FAO, UNEP, WHO, and WOAH. 2022).

Environment

The natural world or physical surroundings in general, either as a whole or within a particular geographical area (FAO, UNEP, WHO, and WOAH. 2022). Darwin used the phrase 'conditions of life', to cover the notion of 'environment' and also workings of life forms. Darwin used the words 'habitat' and 'habitation' which are encompassed by 'environment'. Environment includes the physical and biotic environment where biotic environment refers to associations between life forms

Environmental degradation
The deterioration in environmental quality from ambient concentrations of pollutants and other activities and processes, such as improper land use and natural disasters (FAO, UNEP, WHO, and WOAH. 2022).

Environmental determinants of health
External environmental factors, not related to behaviour, at global, regional, national and local level, which influence the health status of humans and animals, including physical, chemical and biological factors.(FAO, UNEP, WHO, and WOAH. 2022).

Environmental health
The branch of public health concerned with studying and regulating factors in the environment that affect human health and disease and those with alleviating detrimental effects; often attributive; (also) the general condition of the natural environment (FAO, UNEP, WHO, and WOAH. 2022).

Epidemic infectious disease
An outbreak of a disease that spreads quickly and affects one or more populations at the same time in a small geographic area. (FAO, UNEP, WHO, and WOAH. 2022).

Epidemiological triangle
A conceptual model that represents how infectious and non-infectious disease emerge and persist in living systems due to factors in (1) hosts or disease bearers, (2) agents or sources of harm and (3) the environment or conditions affecting exposure Centers for Disease Control and Prevention. (2012). *Principles of epidemiology in public health practice: An introduction to applied epidemiology and biostatistics (3rd ed.)*. U.S. Department of Health and Human Services. https://www.cdc.gov/csels/dsepd/ss1978/

Epigenetics
(see also expressivity as in gene expression and penetrance)
1. The study of the effects of reversible chemical modifications to DNA and/or histones on the pattern of gene expression. Epigenetic modifications do not alter the nucleotide sequence of DNA (Pierce, 2020).
2. Refers to phenomena due to alterations in DNA that do not include changes in the base sequence; often affects the way in which DNA sequences are expressed. Such alterations are often stable and heritable in the sense that they are passed to descendant cells or individuals (Klug et al, 2020).

3. Epigenetics can be defined at the macromolecular level as the ‘sum of the alterations to the chromatin template that collectively establish and propagate different patters of gene expression (transcription) and silencing from the same genome’ (Allis et al, 2015).
4. Epigenetics is the study of heritable and stable changes in gene expression that occur through alterations in the chromosome rather than in the DNA sequence. Despite not directly altering the DNA sequence, epigenetic mechanisms can regulate gene expression through chemical modifications of DNA bases and changes to the chromosomal superstructure in which DNA is packaged (Aboud et al, 2025).

Epistasis (Bateson, 1907)—nonreciprocal interaction of genes at the same gene locus (allelic) or at different gene loci (nonallelic) that alter the phenotypic expression of a gene (Passarge, 2007).

Epistemology
1. One of four branches in philosophy: Epistemology (from Greek *episteme,* ‘knowledge’, and *logos,* ‘explanation’), the study of the nature of knowledge and justification; specifically, the study of (a) the defining features, (b) the substantive conditions or sources, and (c) the limits of knowledge and justification (Audi, 1999).
2. The philosophical study of the nature, origin, and limits of human knowledge. The name is derived from the Greek *epistēmē* (knowledge) and *logos* (reason), and accordingly the field is sometimes referred to as the theory of knowledge (*T*he New Encyclopedia Britannica, 15th Edition, 2007).

Equation
1. In chemistry, a representation of a chemical reaction [FUNCTION] using the symbols of the elements to represent the actual atoms or molecules taking part in the reaction [FORM] (Uvarov and Chapman, 1951).
2. In mathematics, a statement of equality between known and unknown quantities true only for certain values of unknown quantities [FORM] (Uvarov and Chapman, 1951). Equations convert unknown quantities into known quantities [FUNCTION].

Ethics
1. One of four branches in philosophy: Ethics**,** the philosophical study of morality. The word is also commonly used interchangeably with ‘morality’ to mean the subject matter of this study; and sometimes it is used more narrowly to mean the moral principles of a particular tradition, group, or individual (Audi, 1999).
2. Ethics also called moral philosophy is the discipline concerned with what is morally good and bad, right and wrong (The New Encyclopedia Britannica, 2007).

Eugenics
Study of the ways in which the physical and mental quality of a people can be controlled and improved by selective breeding, and the belief that this should be done. The idea was abused by the Nazi Party in Germany during the 1930s to justify the attempted extermination of entire groups of people (Lafferty and Rowe, 1993).

Eusociality
A social organisation that includes reproductive division of labor, cooperative brood care, and overlap of generations (Keller and Chapuisat, 2014).

Evolution
(See also convergent evolution, divergent evolution, coevolution, theory of evolution by natural selection)
1. The phenomenon of evolution refers to changes [modifications] over successive generations in the hereditary characteristics (traits) of populations (groups) of organisms or life forms such as viruses, viroids and prions that are related by descent (lineage) and which extends to and includes all levels in the organisation spectrum from genetic systems to ecosystems; see Section 2 – Setting the Scene (precising definition). The phenomenon of evolution is driven by the process of natural selection.
2. Changes in proportions of biological types in a population over time (Millstein, 2017).
3. Evolution refers to changes in time within population of life forms, including viruses and prions, over generations (adapted from Gluckman et al., 2017: precising definition). Evolution stands above macroevolution and microevolution, which compose a continuum and are not distinct processes, and which refer to areas of interest in evolutionary biology and do not relate to the substance of theory of evolution by natural selection.
4. Evolution incorporates coevolution which refers to reciprocal evolutionary change among interacting species driven by natural selection (Thompson, 2014).

Evolvability
The capacity to undergo evolutionary change. The presence of heritable variation in an organism, virus or prion that can be subjected to natural selection (precising definition).
The capacity for something to possess and generate adaptive diversity and to evolve through natural selection (Kirschner and Gerhart, 1998; Brookfield, 2009).

Exaptation
(see Adaptation)
1. A trait that initially carries out one function and is later co-opted for a new function. The original function may or may not be retained (Zimmer and Emlen, 2016).
2. The evolution of a function of a gene, tissue, or structure other than the one it was originally adapted for; can also refer to the adaptive use of a previously nonadaptive trait (Futuyman and Kirkpatrick, 2017).
3. Co-option of a character by natural selection for a biological role other than one through which the character evolved by natural selection (Larson, 2014).

Expert system

A computer program capable of performing at the level of a human expert in a narrow domain. Expert systems have five basic components: the knowledge base, the database, the inference engine, the explanation facilities and the user interface (Negnevitsky, 2011).

Expressivity
(Also gene expression)
Refers to the degree to which a phenotype for a given trait is expressed (Klug et al, 2020) and plays a part in epigenetic inheritance (see epigenetics).

Figurative language
Language that departs from the literal use of words to evoke feelings and to create an emotional impact. Figurative language employs connotations and figures of speech such as metaphors, similes, personifications, hyperboles, euphemisms, ironies and allusions (precising definition).

Fitness
1. Seen as the combined effect of viability and reproductive ability [viability refers to the ability to survive and live successfully](Nicholas, 1995).
2. The success of an organism at surviving [that is, being viable] and reproducing and thus contributing offspring to future generations (Zimmer and Emlen, 2016).
3. Precising definition: The success of an organism or biological entity, such as a virus or prion, at being viable and surviving and then contributing descendants to future generations. [Fitness springs from the possession by a life form of adaptations apposite for its environment.]

Fomites (fomes, singular)
Any material that can mediate the transmission or communication of an infectious disease (precising definition).

Food chain
(also food web)
Sequence of organisms within an ecosystem in which each is the food of the next member in the chain. A chain starts with the primary producers, whichare photosynthetic organisms (e.g. algae, plants, bacteria) or chemolithotrophicbacteria. These are eaten by herbivores (primary consumers) which are in turn eaten by carnivories (secondary consumers). Small carnivores may be eaten by larger carnivores; *see also* food web (Lawrence, 2008).

Food safety
Assurance that food will not cause adverse health effects to the consumer when it is prepared and/or eaten according to its intended use (FAO, UNEP, WHO, and WOAH. 2022).

Food security
When all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, UNEP, WHO, and WOAH. 2022).

Food security comes from sustainable food system (SFS), which is a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases for food and nutrition are not compromised for future generations. This means that the food production system is profitable throughout the food supply chain (economic sustainability), has broad-based benefits for society (social sustainability) and has a positive or neutral impact on the natural environment (environmental sustainability).

Food systems
Complex and multidimensional webs of activities, resources and actors involving the production, processing, handling, preparation, storage, distribution, marketing, access, purchase, consumption and loss and waste of food, as well as the outputs of these activities, including social, economic and environmental outcomes (FAO, UNEP, WHO, and WOAH. 2022).

Food webs
The interconnected food chains in an ecosystem (Lawrence, 2008).

Formula
In chemistry, the representation of a molecule or smallest portion of a compound, using symbols for the atoms of the elements that make up the compound [FORM and FUNCTION] (Uvarov and Chapman, 1951).
In mathematics and physics, a statement of facts in a symbolical or general form (FORM], by substitution in which a result applicable to a particular data may be obtained [FUNCTION] (Uvarov and Chapman, 1951).

Function
1. Refers to the specific role or activity performed by a structure, molecule, or process that contributes to the viability of a life form (precising definition).
2. The normal or characteristic action of anything; esp., any of the natural, specialized actions of an organ or part of an animal or plant (Webster's). The kind of action or activity proper [pertaining] to a person, thing or institution (Macquarie). The normal or characteristic action of anything; esp., any of the natural, specialized actions of a system, organ, or part of an animal or plant (Collins). Activity proper to anything, mode of action by which it fulfils its purpose (Concise Oxford). Activity and role assigned to something (Rooney, 1999).

Gene
Denotes the basic unit of heredity and has a physical manifestation in the chemical structure of the informational macromolecules that make up the genome of a life form, and which can be DNA (deoxyribonucleic acid), RNA (ribonucleic acid) or protein in the case of prions. Genes contain the instructions for making a specific protein or set of proteins (precising definition).

Gene locus
Morgan, Sturtevant, Muller, Bridges, 1915 —the position of a gene on a chromosome (Passarge,

2007).

Genetic diversity
Variability within a species due to genetic differences between individuals (Lawrence, 2008).

Genetic drift
1. Random changes in gene frequency of a population (Passarge, 2007; attributed to Wright, 1921).
2. Random changes in gene frequency in small isolated populations owing to factors other than natural selection, such as sampling of only a small number of gametes in each generation. *alt.* Sewall Wright effect; (2) random nucleotide changes in a gene not subject to natural selection; (3) small changes in the genome of the influenza virus that cause annual outbreaks but not serious epidemics or pandemics. *cf.* genetic shift (Lawrence, 2008).
Note: The word random in the two definitions above does not mean that genetic drift is somehow exempt from the attributes, properties, elements, conceptions and characteristics that identify and mediate life. The proposition that some mutations (nucleotide changes) are 'not subject to natural selection' is an assumption that served as a convenience in the field of quantitative genetics.

Genetic shift
Diversity in viral genomes that arises as a result of re-assortment of genome segments or recombination between genomes (Flint et al., 2015).

Genetic variation
Heritable variation in a population of life forms resulting from the presence of different variants (alleles) of genes and, in eukaryotes, the shuffling of alleles into new combinations by sexual reproduction and recombination (adapted from Lawrence, 2008).

Genetics
The study of heredity and the variation of inherited characteristics.

Genome
(1) The complete set of genes carried by an organism or virus. If specified quantitatively in respect of a diploid organism, it usually refers to the haploid set of genes;
(2) sometimes refers to the total DNA content of a nucleus (Lawrence, 2008).
(3) All of the genetic material of a cell or of an individual (Passarge, 2007).
(4) Genomes are the entire set of genes specified in physical form by the associated set of informational macromolecules that predominate in a life form (precising definition).

Genotype
(1) The genetic constitution of an organism or a virus (modified from Lawrence, 2008).
(2) All or a particular part of the genetic constitution of an individual or a cell (cf. phenotype): from Johannsen (1909) in Passarge (2007). [Reaction norms are the range of phenotypes possible from a given genotype].

(3) The genotype mirrors the genome and refers to the genetic composition of a life form (precising definition).

Germ
(Sources for this entry are at section 2.4.2b)
1. An ‘element that can develop in the likeness of the form from which it sprang’,
2. ‘That portion of an organic being [life form] which is capable of development into the likeness of that from which it sprang’
3. ‘The rudiment of a new organism’.

Germ Theory
A unifying concept that all infectious diseases are caused by germs or agents that possess the fundamental capabilities of life. The agents involved in infectious disease include prions, viruses, bacteria (monerans), protozoa (protistans), fungi and, nowadays, metazoan endoparasites and exoparasites. A ‘germ’ is an ‘element that can develop in the likeness of the form from which it sprang’, ‘that portion of an organic being [life form] which is capable of development into the likeness of that from which it sprang’ or ‘the rudiment of a new organism’.

Global health security
Global health security considers all activities required, both proactive and reactive, to minimize the impact of global health threats that endanger the health of humans, animals, plants and their environment across geographical regions and international boundaries (FAO, UNEP, WHO, and WOAH. 2022).

Global warming
(see also climate change, greenhouse effect)

- Global warming is the long-term heating of Earth’s surface observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth’s atmosphere. This term is not interchangeable with the term "climate change."
- Since the pre-industrial period, human activities are estimated to have increased Earth’s global average temperature by about 1 degree Celsius (1.8 degrees Fahrenheit), a number that is currently increasing by more than 0.2 degrees Celsius (0.36 degrees Fahrenheit) per decade. The current warming trend is unequivocally the result of human activity since the 1950s and is proceeding at an unprecedented rate over millennia (https://science.nasa.gov/climate-change/what-is-climate-change/).

Greenhouse effect
(see also climate change, global warming)

The greenhouse effect is a natural process that warms the Earth's surface. When the Sun's energy reaches the Earth's atmosphere, some of it is reflected back to space and some is absorbed and re-radiated by greenhouse gases (https://www.dcceew.gov.au/climate-change/policy/climate-science/understanding-climate-change).

Group selection
Selection occurring within the environmental context of a group or subpopulation and arising from variation in fitness among groups and the selection of attributes that benefit the group or subpopulation and which spillover to its individual members. A group is a vague term referring to a set of things that can be classed together according to given criteria. Note that selection of genotypes operates through the selection of phenotypes.

Habitat
The environment within which an organism is normally found. A habitat is characterized by the physical characteristics of the environment and/or the dominant vegetation or other stable biotic characteristics. Examples of habitats can be as general as lakes, woodland or soil, ormore specific, such as mudflats, the bark of an oak tree, chalk downland. *cf.* Niche (Lawrence, 2008).

Hazard
A biological, chemical or physical agent or condition with the potential to cause harm (World Organisation for Animal Health, 2019).

Health
(generic definition; Rooney, 1999)
Overall condition of something; The general condition of something in terms of soundness, vitality and proper functioning.

Health of the environment
The extent to which the environment is able to function, maintain biological and chemical processes, adapt to change or cope with the impacts of human activity (FAO, UNEP, WHO, and WOAH. 2022).

Health system
A system consisting of all organizations, people and actions whose primary intent is to promote, restore or maintain health FAO, UNEP, WHO, and WOAH. 2022).

Herbivory
A form of nutrition in which an organism principally eats autotrophs such as plants, algae and photosynthesizing bacteria (https://en.wikipedia.org/wiki/Herbivore).

Heredity
(1) The genetic constitution of an individual; (2) the transmission of genetically based, and epigenetically based characteristics from parents to offspring (adapted from Lawrence, 2008)

Heritability
(Lush, 1950; Falconer, 1960)—the ratio of additive genetic variance to the total phenotypic variance. Phenotypic variance is the result of the interaction of genetic and non-genetic factors in a population (Passarge, 2007).
The capacity for being transmitted from one generation to the next (Lawrence, 2008).
The capability of genetic material and its associated information for being transmitted from generation to generation (precising definition).

Heuristic
An intelligent trial-and-error approach, as opposed to a rigid algorithmic method [FORM]. Heuristics are used in computer programs which can learn from experience in fields such as machine learning and artificial intelligence, and their non-rigorous nature is also suited to expert systems [FUNCTION](Clugston, 2014).

Holobiont
A host and all its associated endo-symbiotic organisms and viruses. Ruminants such as cattle and sheep are classic holobionts and the association exemplifies mutualism (precising definition).

Homeostasis
A self-regulating process by which a cellular organism can maintain internal stability while adjusting to changing external conditions (Billman, 2020).

Horizontal gene transfer
(see also lateral gene transfer)
(1) Horizontal gene transfer (HGT) is the movement of genetic information between organisms [or viruses], a process that includes the spread of antibiotic resistance genes among bacteria (except for those from parent to offspring), fueling pathogen evolution. HGT occurs by three well-understood genetic mechanisms transformation, conjugation and transduction (adapted from Burmeister, 2015). Horizontal gene transfer drives the antigenic shift described for influenza viruses (see antigenic shift).
(2) The transfer of genetic material and information among life forms by means other than the process of reproduction and transmission of genetic material and information from parent to offspring in a single given species. Horizontal gene transfer may involve mobile genetic elements such as plasmids, prophages, pathogenicity islands, restriction and modification systems, transposons, and insertion sequences (precising definition).

Host
(See also spillover infection)
General definition: The larger participant in a symbiotic relationship serving as a home and feeding ground for the smaller participant (Campbell and Reece, 2022).
Definition from parasitology: An animal or plant that harbours and provides sustenance for another organism (the parasite)(Gosling, 2005).

Types of host:
Bridge host: Bridge hosts are those that provide a link through which pathogens can be transmitted from maintenance host populations or communities to receptive populations that require protection (i.e., target hosts)(Caron et al., 2015).
Dead-end host: Also known as accidental of incidental hosts. 1. A host from which infectious agents are not transmitted to other susceptible hosts. 2. Any host organism from which a parasite cannot escape to continue its life cycle (O'Toole, 2013).
Definitive host: Also known as primary host. Host in which a parasite achieves sexual maturity. If there is no sexual reproduction in the life of the parasite, the host most important to humans is the definitive host (Schmidt and Roberts, 2009).
Intermediate host: Also known as secondary host. Host in which a parasite develops to some extent but not to sexual maturity (Schmidt and Roberts, 2009).
Maintenance host: Host population (single population) or community/host complex (several sympatric host populations) 'in which the pathogen persists even in the complete absence of transmission from other hosts' (Caron et al., 2015)
Mixing vessel host: In virology, a host that can be infected simultaneously with more than one subpopulation of a viral species (see precising definition of species) and where horizontal transfer of genetic information between subpopulations can occur and can thereby generate new subpopulations with new capabilities (see Scholtissek, 1987).
Paratenic host: Also known as transport host or transfer host. Host in which a parasite survives without undergoing further development (Schmidt and Roberts, 2009).
Permissive host: A host that possesses permissive cells or cells in which replication of a particular virus species can take place. Non-permissive hosts are hosts that do not possess cells in which replication of a particular virus species can take place (precising definition).
Reservoir host: One or more epidemiologically connected populations or environments in which the pathogen can be permanently maintained and from which infection is transmitted to the defined target population (Caron et al., 2015). one or more epidemiologically connected populations or environments in which the pathogen can be permanently maintained and from which infection is transmitted to the defined target population (Haydon et aL., 2002). A host in which a given pathogen usually dwells and is maintained as source of infection to other host species (precising definition).

Host range
In virology: A listing of species and cells (hosts) that are susceptible to and permissive for infection (Flint et al., 2015).
In general biology: The range of different species, or cell types, that a pathogen can infect (Lawrence, 2008).

Human health
Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief,

economic or social condition.The health of all peoples is fundamental to the attainment of peace and security and is dependent on the fullest co-operation of individuals and States (WHO).

Hypernym

A hypernym is a word with a broad meaning that identifies a category which covers words with more specific meanings. See Concept – superordinate.

Hyponym

A hyponym is a word that is narrower and more specific in meaning than a hypernym (precising definition).

Hypothetico-deductive reasoning

1. A method for problem-solving whereby hypotheses based on observations or existing knowledge are put to the test by further observations, designed studies such as experiments and critical thinking.
2. The method particularly associated with the philosophy of science that stresses the virtues of falsification. Most simply, a hypothesis is proposed, and consequences are deduced, which are then tested against experience. If the hypothesis is falsified, then we learn from the attempt, and are in a position to produce a better one. If not, then we can try other tests (Blackburn, 2016).

Inbreeding

Mating of closely related individuals. The opposite is outbreeding, the mating of unrelated organisms. Inbreeding is useful in keeping desirable characteristics or eliminating unreliable ones, but it often results in decreased vigour, size and fertility of offspring because of the combined effects of harmful genes that were recessive in both parents (Britannica Concise Encyclopedia, 2006).

Individual Selection

Selection generated by variation in the reproductive success of individual organisms.

Infection

(precising definition)

(see also contagion, infestation and persistent/latent/chronic/silent infection)

1. The process of implanting an infectious disease agent into the body of a host. Infectious disease agents include biological entities (germs) such as prions, viruses, bacteria (monerans), protozoa (protistans), fungi and metazoan endoparasites and ectoparasites.
2. The presence of an infectious disease agent in the body of a host.
3. The association between an infectious disease agent and a host.
4. The communication or transmission of a disease from one subject to another.
5. The establishment of a pathogen in its host after invasion.

Infectious

(precising definition)

1. Capable of being transmitted by infection with or without actual contact.
2. Caused by infection of the body by infectious disease agents such as prions, viruses, bacteria (monerans), protozoa (protistans), fungi and metazoan endoparasites and ectoparasites.

Infectious disease
(precising definition)
A disease resulting from the presence and activity of an infectious disease agent. Infectious disease agents include biological entities (germs) such as prions, viruses, bacteria (monerans), protozoa (protistans), fungi and metazoan endoparasites and ectoparasites (adapted from Stedman's, 2006).

Infectivity
1. The characteristic of a disease agent that embodies capability to enter, survive and multiply in a host. A measure of infectivity is the secondary attack rate.
2. The proportion of exposures, in defined circumstances, that results in infection (Last, 1988).

Infest, infestation
(precising definition)
Infest: To attack, invade, and subsist on the skin or in the internal organs of a host. In contrast, infect is to transmit a pathogen that may induce development of an infectious disease in another person.
Infestation: Presence of animal parasites in the environment, on the skin, or in the hair of a host. (from O'Toole, 2013).

Inform, information
Inform: to give form or shape to; to give vital or organizing power to; to give life to; to imbue and actuate with vitality; to animate; to mold; to figure; to fashion.
Information: The abstraction that gives form or shape to; gives vital or organizing power to; gives life to; imbues and actuates with vitality; animates; molds; figures; fashions (Webster' New World Dictionary,1986).

Information technology (**IT**)
An entity extending upon information and communications technology (ICT) and which encompasses computer systems, computer software, programming languages, data management, information processing, and information storage. Information technology is the application product of computer science and computer engineering (see https://en.wikipedia.org/wiki/Information technology).

Informational macromolecules
Molecules that store the genetic material necessary for inheritance and the management and processing of genetic information required by life forms. Informational macromolecules are DNA for eukaryotes and prokaryotes, various forms of DNA or RNA for viruses and proteins for prions (precising definition).

Inheritance (heritability)
1. Refers to the transmission and reception of genetic information from generation to generation via processes of reproduction (see section 4.3.3: precising definition).

Integrated pest management
The careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment (FAO:
https://www.fao.org/pest-and-pesticide-management/ipm/integrated-pest-management/en/)

Integrated vector management
A rational decision-making process to optimize the use of resources for vector control (FAO, UNEP, WHO, and WOAH. 2022).

Intelligence
Intelligence refers fundamentally and plainly to the capacity to acquire and apply knowledge and skills (Apple Dictionary app, Apple.com). This meaning need not refer exclusively to humankind and can cover the intelligence possible in living organisms, machines and hypothetical extraterrestrial entities. The American Psychological Associations (https://dictionary.apa.org/) refers to intelligence as the ability to derive information, learn from experience, adapt to the environment, understand, and correctly utilize thought and reason (VandenBos, 2015).
Precising definition: A system's ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation (adapted from Russell and Norvig, 2010; Negnevitsky, 2011; Ertel, 2017; and Neapolitan and Jiang, 2018). Put more simply, intelligence is the ability to learn coupled with flexibility in behaviour (Burnie, 2001).

Intermediate host
(see host)

Kin selection
Selection occurring within the environmental context of a group or subpopulation related by kinship, pedigree or ancestry and arising from a diversity in fitness attributes or traits and the selection of attributes or traits which benefit that group or subpopulation and which spillover to its individual members (precising definition).

Knowledge base
A basic component of an expert system that contains knowledge about a specific domain (Negnevitsky, 2011).

Knowledge-based system
A system that uses stored knowledge for solving problems in a specific domain. A knowledge-based system is usually evaluated by comparing its performance with the performance of a human expert (Negnevitsky, 2011).

Knowledge economy
(see also open science and learning society)
The knowledge economy, or knowledge-based economy, is an economic system in which the production of goods and services is based principally on knowledge-intensive activities that contribute to advancement in technical and scientific innovation (Wikipedia, https://en.wikipedia.org/wiki/Knowledge_economy).

Knowledge engineering
The process of building a knowledge-based system. There are six main steps: assess the problem; acquire data and knowledge; develop a prototype system; develop a complete system; evaluate and revise the system; integrate and maintain the system (Negnevitsky, 2011).

Knowledge representation
The process of structuring knowledge to be stored in a knowledge-based system. In AI, production rules are the most common type of knowledge representation (Negnevitsky, 2011).

Language
1. The principal method of human communication, consisting of words used in a structured and conventional way and conveyed by speech, writing, or gesture. A system of communication used by a particular country or community (Apple Dictionary).
2. Language is a specific system of communication characterised by its use of structured symbols, such as words and grammar, to convey complex and abstract ideas. It is primarily used by humans and is distinguished by its infinite productivity and creativity, allowing for the expression of an unlimited range of experiences and ideas. All language is a form of communication. However, communication does not necessitate language (https://www.britannica.com/science/animal-communication).

Laws (in Science)
Laws in science describe or predict various phenomena in nature and are defined as statements of a relation or sequence of phenomena invariable under the same conditions (*Macquarie Encyclopedic Dictionary*; Delbridge, 1990). According to the National Academy of Sciences (1998), a law in science is a 'descriptive generalization about how some aspect of the natural world behaves under stated circumstances'.

Learning society
(see also open science and knowledge economy)
The learning society is an educational ideal proposed by the OECD and UNESCO which centres education as the key to a nation's economic development, and holds that education should extend

beyond formal learning (based in traditional educational institutions – schools, universities etc.) into informal learning centres to support a knowledge economy (known as a "world education culture").

Levels of selection

1. Refers to the several kinds of reproducing biological entities (e.g., genes, organisms, species) that can vary in fitness, resulting in potential selection among them (Futuyma and Kirkpatrick, 2017).
2. 'While it would seem self-evident that selection acts at the level of the individual, since it is the phenotype of the individual which determines whether that particular individual reproduces within an environment, a range of other possibilities need to be considered (Okasha 2006). In theory selection can act at any level of biological organization if there is differential survival associated with that level (Gluckman et al., 2017).

Life (eukaryotes and prokaryotes)

Cellular organisms within the five kingdoms of life are entities with capabilities for agency and the management, representation and processing of information that allow them per se to perform and exhibit the essential properties and characteristics of life, which are organisation and self regulation, metabolism, responsiveness, movement, growth, development, reproduction, life-cycling and evolutionary adaptation (precising definition).

Life (sub-cellular entities, viruses and prions).

Sub-cellular life forms or organic beings exemplified by viruses and prions are entities with capabilities for agency and the management, representation and processing of information that allow them to manipulate the cellular machinery of prokaryotes and eukaryotes and thereby perform and exhibit the essential properties and characteristics of life, which are organisation and self regulation, metabolism, responsiveness, movement, growth, development, reproduction, life-cycling and evolutionary adaptation (precising definition).

Life (precising definition)

Life as a phenomenon is present in life forms and living systems and entails capabilities for agency and information management that control the transformations of energy and material necessary for vital functions or processes that actuate, implement and sustain the phenomenon. Capabilities for agency and information management enable eukaryotic and prokaryotic cellular organisms to employ their intrinsic cellular machinery and implement *per se* an overlapping, interrelated and comprehensive set of vital functions comprising various forms of organisation, self-regulation, nutrition, metabolism (transformations of matter and energy), respiration, excretion, responsiveness, homeostasis, movement, life-cycling (growth, development and reproduction) and evolutionary adaptation. Capabilities for agency and information management enable sub-cellular life forms, organic beings or bionts (exemplified by viruses and prions) to associate with prokaryotes and eukaryotes and exploit the comprehensive and set of vital functions in these cellular organisms to

implement the particular vital functions of reproduction and evolutionary adaptation. Associations with viruses or prions can range from beneficial to harmful for cellular organisms.

Life cycle
Refers to the sequence of changes in a life form as it passes from a given developmental stage to the same developmental stage in the following generation.

Linguistics
The study of human language: how languages are used to communicate, how languages vary and change over time, how meanings are expressed, how children and adults acquire language, and how communication differs across communities (https://programsandcourses.anu.edu.au/major/ling-maj).

Logic
1. The central topic of logic is valid reasoning, its systematization and the study of notions relevant to it. This gives it two systematically related areas of concern, formal logic and philosophical logic (also called logical theory, though usage varies and philosophy of logic is sometimes confined to the study of logical systems and their applications)(Blackburn, 2016).
2. Logic is the study of good reasoning. It's not the study of reasoning as it actually because people can often reason badly. Instead, in logic, we study what makes good reasoning good (Restall, 2003).

Machine learning
See also artificial intelligence
1. A subset of artificial intelligence that focuses on the development of algorithms and statistical models that enable computers to learn from and make predictions or decisions based on data without being explicitly programmed for those tasks. Machine learning is a fundamental part of artificial intelligence which incorporates additional factors like reasoning, problem-solving, perception, natural language processing, knowledge representation, planning, decision-making, and adaptability (ChatGPT; https://chat.openai.com/).
2. An adaptive mechanism that enable computers to learn from experience, learn by example and learn by analogy. Learning capabilities improve the performance of an intelligent evolutionary computation system over time. Machine learning is the basis of adaptive systems. The most popular approaches to machine learning are artificial neural networks and genetic algorithms (Negnevitsky, 2011).

Macroevolution
1. Evolution occurring above the species level, including the origination, diversification, and extinction of species over long periods of evolutionary time (Zimmer and Emlen, 2016).
2. A vague term, usually meaning the evolution of substantial phenotypic changes, usually great enough to place the changed lineage and its descendants in a distinct genus or higher taxon. Cf. Microevolution (Futuyma and Kirkpatrick, 2017).

3. Macroevolution—the process underpinning speciation and biodiversity—is not central to a medical perspective [on evolutionary biology] (Gluckman et al., 2017). Macroevolution and microevolution refer to areas of interest in evolutionary biology and do not relate to the substance of theory of evolution by natural selection.
4. Evolutionary change over relatively long time periods due to natural selection in life forms and changes in their informational macromolecules (i.e. microevolution) and which leads to the emergence of new species and extensions to taxonomic groups (precising definition).

Maintenance host
(see host)

Maladaptation
(see Adaptation)
Defined as a condition in which biological traits or behavior patterns are detrimental, counterproductive, or otherwise interfere with optimal functioning in various domains, such as successful interaction with the environment and effectual coping with the challenges and stresses of daily life (American Psychological Association, https://dictionary.apa.org/).

Mechanism
1. The way something works (Rooney, 1999).
2. An instrument or a process, physical or mental, by which something is done or comes into being (American Heritage Dictionary, https://ahdictionary.com/word/search.html?q=mechanism). 1 and 2 amalgamate as precising definition).

Metabolism
1. The sum of the chemical processes by which cells produce the materials and energy necessary for life. Metabolism has two phases: (1) anabolism, or constructive metabolism, during which cells combine molecules to assemble new organic materials, and (2) catabolism, or destructive metabolism, during which cells break down molecules to obtain energy and release heat. All organisms conduct both phases constantly.
2. The integrated network of biochemical reactions that supports viability in living organisms and biological entities such as viruses and prions (modified from Lawrence, 2008).

Metaphysics
1. One of four branches of philosophy: Metaphysics most generally, the philosophical investigation of the nature, constitution, and structure of reality. It is broader in scope than science, e.g., physics and even cosmology (the science of the nature, structure, and origin of the universe as a whole), since one of its traditional concerns is the existence of non-physical entities (Audi, 1999).
2. Branch of philosophy concerned with critically examining basic philosophical assumptions and identifying what exists insofar as it exists (The New Encyclopedia Britannica, 2007).

Miasma

Poisons in the air, exuded from rotting animal and vegetable material, the soil and standing water that were considered to be the cause of infectious disease (precising definition).

Microevolution
(see also Macroevolution)

1. Evolution at or below the species level [extending to evolution at the level of genetic systems and informational macromolecules](inspired by Mayr, 2002).
2. Evolution occurring within populations, including adaptive and neutral changes in allele frequencies from one generation to the next (Zimmer and Emlen, 2016).
3. A vague term, usually referring to slight, short-term evolutionary changes within species. Cf. macroevolution (Futuyma and Kirkpatrick, 2017).
4. 'Importantly, macroevolution and microevolution are a continuum, not distinct processes. Classically, evolution is therefore defined a "change in time within a population of organisms [viruses, prions] over generations:' (Gluckman et al., 2017). Microevolution and macroevolution refer to areas of interest in evolutionary biology and do not relate to the substance of theory of evolution by natural selection.
5. Evolution or descent with modification due to natural selection within species of life forms and marked by changes in their informational molecules. The action of microevolution over time leads to macroevolution and the emergence of new species and extensions to taxonomic groups (precising definition).

Microorganism

1. A microscopic organism (Macquarie Dictionary).
2. General term for bacteria, viruses, unicellular algae and protozoans, and microscopic fungi (yeasts and moulds), which are all of microscopic or ultramicroscopic size. *alt.* Microbe (Lawrence, 2008).

Mind map

Mind maps are enigmatic and have been publicised but not been explained by expository and disinterested discourse (Buzan, 2006 and 2024) A mind maps may be equivalent to a concept map or a concept schema.

Mixing vessel host

(see host).

Mobile genetic element

1. See transposable genetic elements (Lawrence, 2008).
2. Mobile [genetic] element is a generic term for a multitude of genomic sequences, such as plasmids, prophages, pathogenicity islands, restriction and modification systems, transposons, and insertion sequences, among others, that share the ability to be transmitted vertically with cell division or through horizontal transfer (Vale et al., 2022).

3. Mobile genetic elements are sequences of genetic material that can change places on a chromosome, and be exchanged between chromosomes, between bacteria, and even between species (Foxman, 2012).

Model

In science, a physical, conceptual, or mathematical representation of a real phenomenon that is difficult to observe directly [FORM]. Scientific models are used to explain and predict the behaviour of real objects or systems and are used in a variety of scientific disciplines, ranging from physics and chemistry to ecology and the Earth sciences [FUNCTION]. Scientific models at best are approximations of the objects and systems that they represent—they are not exact replicas (precising definition).

Modern synthesis

Also neo-Darwinism

Generally refers to the early to mid-century formulation of evolutionary theory that reconciled classical Darwinian selection theory with a newer population-oriented view of Mendelian genetics that attempted to explain the origin of biological diversity (Smocovits, 2018).

Müller's ratchet

A process in evolutionary where the absence of recombination as in an asexual population) results in accumulated and irreversible deleterious mutations (precising definition).

Mutagen

Any chemical or physical environmental agent that induces a genetic mutation or increases the mutation rate (O'Toole, 2013).

Mutation

An alteration in the genetic material (the genome) of a cellular organism or virus that can pass from one generation to another. Mutations are a source of diversity that drives evolution. Mutations may occur as large-scale changes such as the loss or rearrangement of a large section of a chromosome or as small-scale changes where there is a substitution, insertion or deletion of one or more nitrogenous base pairs in a section of DNA, or in the case of viruses in nitrogenous bases within sections of either DNA or RNA. Mutations in genetic material alter amino acid sequences in proteins and thus affect viability through gains-of-function or losses-of-function. Frameshift mutations are those where added or deleted nitrogenous bases disrupt the reading frame that guides the processes of transcription and translation. Mutations can occur as copying errors during the replication of informational macromolecules (DNA or RNA) or can be the result of exposure to **mutagens** (precising definition).

Mutualism

A type of interaction between two or more species in which growth and survival of all populations is benefitted and none alone can survive under natural conditions. Mutualism operates in holobionts such as ruminants (adapted from Odum, 1983).

Natural environment
All living and non-living things that occur naturally in a particular region where human impact is kept under a certain limited level (FAO, UNEP, WHO, and WOAH. 2022).

Natural selection
Natural selection is the process that occurs when organisms or biological entities such as viruses and prions interact with their environment according to their nature, or intrinsic characteristics and properties, and that of their environment and its biotic and abiotic elements. Natural selection results in 'descent with modification' or generational change whereby forms of organisms or biological entities in a population that are appropriately adapted (fitted) to an environment increase in frequency relative to less well adapted forms. The process of natural selection works through a means likened to a passive filter where elimination and selection of phenotypes according to their viability results in elimination and selection of the associated genotypes (precising definition). The process of natural selection drives the phenomenon of evolution.
[See also selection pressure and selection advantage].

Naturalistic fallacy
According to Hull (2002c): 'The naturalistic fallacy with respect to morality is reasoning from what *is* the case to what *ought* to be the case. For example, in all societies throughout the history of the human species, men have held most of the power. To conclude from that fact that such patriarchal societies are morally preferable to matriarchal societies, or to societies in which males and female share power equally, is an instance of the naturalistic fallacy.'

Nature and natural
Nature A (Essence) refers to the senses of the intrinsic character of a person or thing or the real appearance or aspect of a person or thing and this usage dates to at least 1828. Nature B (Forces) has the sense of the 'forces controlling the living world' and this usage dates to at least 1828. Nature C (Physical World) has the sense of the physical world including all natural phenomena and living things.

Neglected tropical diseases (NTDs)
Ancient diseases of poverty that impose a devastating human, social and economic burden on more than 1 billion people worldwide, predominantly among the most vulnerable, marginalized populations in tropical and subtropical areas. The NTDs currently prioritized by WHO are a diverse set of 20 diseases and disease groups, namely, Buruli ulcer, Chagas disease, dengue and chikungunya, dracunculiasis, echinococcosis, foodborne trematodiases, human African trypanosomiasis, leishmaniasis, leprosy, lymphatic filariasis, mycetoma, chromoblastomycosis and other deep mycoses, onchocerciasis, rabies, scabies and other ectoparasitoses, schistosomiasis, soil-

transmitted helminthiases, snakebite envenoming, taeniasis/cysticercosis, trachoma and yaws (FAO, UNEP, WHO, and WOAH. 2022).

Neoplasia
1. Formation of new tissue. 2. Formation of tumors or neoplasms (Hoerr and Osol, 1956).

Neutralism
A type of interaction between two species in which neither population is affected by association with the other (Odum, 1983).

Niche
(See also ecological niche and habitat)
In ecology, niche refers the position of a species within an ecosystem and the range of conditions necessary for its persistence and activities. Ecological niches entail all interactions between a species and its abiotic or physical environment and its biotic environment which involves associations among species ranging from predation to cooperative mutualism and which extends to the trophic level occupied by a given species in the food chain and food webs. Two-way interactions occur where the environment affects a species and a species affects its environment and in doing so affects other species (precising definition).

Niche construction
(precising definition)
1. The process whereby organisms, through their metabolism, their activities, and their choices, modify their own and/or each other's niches.
2. A process of involving reciprocity and where organisms alter conditions in their surrounding environment and where the changed conditions impose a selection pressure on other organisms.

Non-permissive host
(see host).

Norm of reaction
See reaction norm.

Objects of selection
During the history of evolutionary biology, objects of selection have been variously labeled as units of selection (Lewontin, 1970), replicators (Dawkins, 1978), or selectons (Mayr, 1997) and are life forms that can evolve because they have three necessary capacities of variation, reproduction, and heritability (Lewontin, 1970; Hull, 1980).

One Health
One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes that the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and

interdependent (WHO, World Health Organization https://www.who.int/health-topics/one-health#tab=tab_1).

Ontological framework

Ontological frameworks provide a structured approach and guidelines for developing, organising, and managing ontologies as formal representations of knowledge [FORM]. Ontological frameworks facilitate consistency and interoperability in representing knowledge and reasoning about knowledge within specific domains or across different domains [FUNCTION]. A domain is a specific area or context (precising definition)

Ontology

1. An ontology for artificial intelligence is 'a representation of knowledge as a set of concepts and relationships that exist among those concepts' (Neapolitan and Jiang, 2018).
2. An ontology is a formal representation of knowledge that describes the entities, concepts, and relationships within a specific domain. It aims to provide a structured and detailed representation of the domain's vocabulary and the semantics of its concepts. Ontologies are used in knowledge engineering, information systems, machine learning, artificial intelligence, and the Semantic Web to enable machine-readable and interoperable knowledge representation (ChatGPT, https://chat.openai.com/).
3. In philosophy: The branch of metaphysics that addresses the nature or essential characteristics of being and of things that exist; the study of being *qua* being (https://en.wiktionary.org/wiki/ontology).
4. Precising definition: Ontologies are employed in information technology (IT) to implement interoperable knowledge protocols and give detailed and reliable explanations of the entities, concepts and their relationships in a given area of interest.

Open science

(see also learning and knowledge economy)

Open science aims to make scientific knowledge openly available, accessible and reusable. It increases scientific collaboration and sharing of information, while opening the processes of scientific knowledge creation, evaluation and communication to societal actors beyond the traditional scientific community. The key elements of open science include: open access to scientific knowledge (including open access to scientific publications, data, educational resources, software and hardware); open infrastructures; open engagement with society and dialogue with indigenous and traditional knowledge systems (UNESCO, https://www.unesco.org/en/open-science).

Organisation

The structured arrangement and interaction of components within a system that determines how structure, function and mechanism integrate to produces capabilities that generate agency or the means by which something is accomplished. It defines the patterns, hierarchies, and networks that regulate function, stability, and adaptability in evolution and disease transmission. Organisation gives meaning to the word 'organism' in biology.

Organism
(see also microorganism)

1. Any living thing (Lawrence, 2008).
2. A synonym for 'biont' or discrete unit of living matter (https://www.merriam-webster.com/dictionary/biont).
3. Organisms classify as cellular or subcellular. Cellular organisms are endowed with cells possessing membranes that that regulate exchanges of matter and energy with the surrounding environment and allow for function as open thermodynamic systems. Subcellular organisms rely on the capabilities of cellular organisms for the energy and material that support their particular modes of life.
4. The word organism incorporates the notion of organisation as intermediary between structure and function in the material world.

Pandemic

An outbreak of a disease that occurs over a wide geographic area (such as multiple countries or continents) and typically affects a significant proportion of the population (FAO, UNEP, WHO, and WOAH. 2022).

Parasitism

1. Like predation, a type of interaction between two species in which one population adversely affects the other by direct attack but nevertheless depends on the other (Odum, 1983).
2. The condition of an organism [or life form such as a virus or prion] living in or on another organism (the host) at whose expense the parasite is maintained, destructive symbiosis (Hickman et al, 2006).
3. Parasites, by extension, are organisms [or life forms such as viruses or prions] that live in or on another organism (the host) at whose expense the parasites are maintained.
4. A symbiotic association between two life forms where one life form, the parasite, benefits at the expense of another organism, the host (precising definition).

Paratenic host

(see host)

Pathogen

1. Any agent which is capable of producing disease. The term is usually restricted to living agents (Hoerr and Osol, 1956).
2. Any organism, agent, factor or process capable of causing disease, literally causing a pathological process (Porta, 2014).
3. A living agent (germ) capable of producing disease in another life form (precising definition).

Pathogenesis

The postulated mechanisms by which the aetiological agent produces disease (Last, 1988).

Pathogenicity
The property of an infectious agent that determines the extent to which overt disease is produced in an infected population (Bennett et al., 2020).

Pathophysiology
(from Wikipedia, https://en.wikipedia.org/wiki/Pathophysiology)
Pathophysiology (or physiopathology) is a branch of study, at the intersection of pathology and physiology, concerning disordered physiological processes that cause, result from, or are otherwise associated with a disease or injury.

Penetrance
1. The frequency, expressed as a percentage, with which individuals of a given genotype manifest at least some degree of a specific mutant phenotype associated with a trait (Klug et al., 2020).
2. The frequency or probability of expression of an allele (cf. expressivity)(Passarge, 2007).

Persistent infection
(Also latent, chronic and slow and silent infection)
Those in which a virus [or other pathogen; e.g. the bacterium *Chlamydia trachomatis*] is not cleared but remains in specific cells of infected individuals. Persistent infections may involve stages of both silent and productive infection without rapidly killing or even producing excessive damage of the host cells. There are three types of overlapping persistent virus-host interaction that may be defined as latent, chronic and slow infection (Boldogh et al., 1996).

Phenotype
1. The visible or otherwise measurable physical and biochemical characteristics of an organism (or biological entity such a virus or prion), resulting from the interaction of genotype and environment (adapted from Lawrence, 2008).
2. All the observable characteristics of an organism (or biological entity such as a virus or prion) that result from the interaction of its genotype (total genetic inheritance) with the environment. Examples of observable characteristics include behaviour, biochemical properties, colour, shape, and size (adapted from https://www.britannica.com/science/phenotype).

Phenotypic plasticity
1. Changes in the phenotype produced by a single genotype in different environments (Zimmer and Emlen, 2016).
2. The range of possible life sustaining capabilities in a given phenotype; see also cline.

Philosophy
(see also epistemology, ethics, logic and metaphysics)
1. Philosophy ('love of wisdom' in Ancient Greek) is a systematic study of general and fundamental questions concerning topics like existence, reason, knowledge, value, mind, and language. It is a

rational and critical inquiry that reflects on its own methods and assumptions (Wikipedia. https://en.wikipedia.org/wiki/Philosophy#References).
2. Philosophy, (from Greek, by way of Latin, *philosophia*, love of wisdom) the critical examination of the grounds for fundamental beliefs and an analysis of the basic concepts employed in the express of such beliefs (The New Encyclopedia Britannica, fifteenth Edition, 2007).
3. Philosophy (from Greek, by way of Latin, *philosophia*, love of wisdom) the rational, abstract, and methodical consideration of reality as a whole or of fundamental dimensions of human existence and experience (https://www.britannica.com/topic/philosophy).

Physiology
Physiology is the science of life. It is the branch of biology that aims to understand the mechanisms of living things, from the basis of cell function at the ionic and molecular level to the integrated behaviour of the whole body and the influence of the external environment (the Physiological Society, https://www.physoc.org/). Physiology can extend to an understanding of the mechanisms operating in biological entities such as viruses and prions (precising definition).

Plasmid
1. Autonomously replicating circular DNA structures found in bacteria. Although they are usually separate from the actual genome, they may become integrated into the host chromosome: From Passarge (2007) and attributed to Lederberg (1952).
2. Small DNA replicating independently of the chromosome in bacteria and unicellular eukaryotes such as yeasts. Plasmids are maintained at a characteristic stable number from generation to generation. They typically carry genes for antibiotic resistance, colicin production or the breakdown of unusual compounds. They are widely used in genetic engineering as vectors into which foreign genes are inserted for cloning or expression in bacterial or yeast cells (Lawrence, 2008).

Polysemy
The coexistence of many possible meanings for a word or phrase (precising definition).

Population
1. A population is any complete group with at least one characteristic in common. Populations are not just people. Populations may consist of, but are not limited to, people, animals, businesses, buildings, motor vehicles, farms, objects or events (Australian Bureau of Statistics: https://www.abs.gov.au/statistics/understanding-statistics/statistical-terms-and-concepts/population).
2. A population is an aggregate of creatures, things, cases and so on (Campbell and Swinscow, 2009).

Portal of entry
The site at which a pathogen enters the host.

Portal of exit
The site at which a pathogen leaves the host.

Predation
Like parasitism, a type of interaction between two species in which one population adversely affects the other by direct attack but nevertheless depends on the other (Odum, 1983).

Prion
1. Prions are infectious proteins: altered forms of a normal cellular protein that may have lost their normal function, but have acquired the ability to change the normal form of the protein into the same abnormal form as themselves.
2. Prions are composed of host-encoded proteins that adopt alternative conformations, which are both self-propagating and infectious. Prions are the product of disordered protein homeostasis (proteostasis)(precising definition).
3. Prions are misfolded proteins arising from failed proteostasis that can trigger other normal proteins to misfold and lead to a cascade of misfolding and consequent disease. Prions can be transmissible and are the causative agents of the rapidly progressive neurodegenerative diseases known as the transmissible spongiform encephalopathies. Prions are implicated in other degenerative diseases such as Alzheimer’s disease, Parkinson’s disease and the non-transmitting form of scrapie disease in sheep (precising definition).

Process
A particular method of doing, achieving or arriving at something, generally involving a number of steps or operations (Webster’s Collegiate Dictionary). A continuous action, operation, or series of changes taking place in a definite manner (Macquarie Dictionary). A series of actions which are carried out in order to achieve a particular result (Collins Dictionary). Course of action, proceeding (Concise Oxford Dictionary). Amalgamates to precising definition.

Program
A program is a concrete implementation of an algorithm using a programming language. It is a collection of instructions written in a specific programming language that can be executed by a computer [FORM]. A program translates the algorithmic steps into a form that a computer can understand and execute [FUNCTION] (precising definition).

Proteostasis
Protein homeostasis or 'proteostasis' is the process that regulates proteins within the cell in order to maintain the health of both the cellular proteome and the organism itself. Proteostasis involves a highly complex interconnection of pathways that influence the fate of a protein from synthesis to degradation (https://www.enzolifesciences.com/platforms/proteostasis/).

Protocol
A protocol within computing or communication refers to the combination of rules and guidelines that govern how data is transmitted and received between devices or systems [FORM]. Protocols set out the format, timing, sequencing, and measures for managing errors that make for successful communication [FUNCTION].
The detailed plan of a scientific experiment, medical trial or other piece of research (Rooney, 1999).

Protozoa
A taxonomic group of single-celled microorganisms that live in almost every kind of habitat and include some pathogenic parasites of humans and other animals (http://needtoknow.nas.edu/id/glossary/).

Quality management
A quality management system (QMS) is defined as a formalized system that documents processes, procedures, and responsibilities for achieving quality policies and objectives. A QMS helps coordinate and direct an organization's activities to meet customer and regulatory requirements and improve its effectiveness and efficiency on a continuous basis.
ISO 9001:2015, the international standard specifying requirements for quality management systems, is the most prominent approach to quality management systems (https://asq.org/quality-resources/quality-management-system).

Quasispecies
Viral quasispecies are dynamic distributions of nonidentical but closely related mutant and recombinant viral genomes subjected to a continuous process of genetic variation, competition, and selection that may act as a unit of selection. The quasispecies concept owes its theoretical origins to a model for the origin of life as a collection of mutant RNA replicators (Domingo et al., 2021).

Reaction norms
(also norms of reaction)
1. Patterns of phenotypic expression of a single genotype across a range of environments. In a sense, reaction norms depict how development maps the genotype into the phenotype as a function of the environment (Zimmer and Emlen, 2016).
2. Reaction norms are the range of phenotypes possible from a given genotype.

Reassortant viruses
Viruses that have different segments in their genomes derived from two (or more) parent viruses and which express some viral proteins from one strain and some viral proteins the other strains. Reassortment can occur at high frequency with viruses that have fragmented genomes.

Reassortment
Reassortment, like recombination, is a form of exchange of genetic material within a species that leads to individuals with new combinations and new capabilities. Reassortment applies to RNA viruses with segmented genomes where recombination occurs between segments. Reassortment is responsible for genetic shifts that allow the evolution and emergence of new forms of viral diseases like influenza (derived definition).

Recipe

List of ingredients and instructions [FORM] for making something, especially for (but not restricted to) a food dish [FUNCTION]. A method for doing something or a combination of circumstances likely to bring something about (Rooney, 1999).

Recombinants
Viruses containing nucleic acid sequences from two or more different virus genomes. They may be formed naturally in either of two ways: intramolecular recombination, which involves transfer of sequences within single molecules of nucleic acid, or genetic reassortment, in which viruses whose genomes are fragmented into a number of pieces (e.g. Arenaviridae, Bunyaviridae, Orthomyxoviridae, or Reoviridae) exchange whole pieces (segments) of RNA)(Mahy, 2009)

Recombination
1. The process where informational macromolecules (DNA and RNA) split and then recombine to form new genes or allele combinations. In eukaryotes, homologous recombination occurs at regions of sequence similarity during meiosis and gamete formation. Recombination also occurs at non-homologous sites in somatic cells by means of transposons or mobile genetic elements that can move between positions in the one genome. In prokaryotes, recombination is a mechanism for horizontal gene transfer whereby free extracellular DNA is integrated into genomes by means of transformation (the uptake of free or naked DNA present in the environment), transduction (which involves a viral vector) and conjugation (where one prokaryote receives DNA from another prokaryote via cell surface organelles). Recombination occurs in RNA viruses when more than one viral genome is present in the same host cell. The result is increased diversity that includes the capacity to evade host immune responses (precising definition).
2. The exchange of genetic material from two or more virus particles into recombinant progeny virus during a mixed infection (Mahy, 2009).

Regenerative agriculture
Regenerative agriculture is a way of farming that focuses on soil health. When soil is healthy, it produces more food and nutrition, stores more carbon and increases biodiversity – the variety of species. A teaspoon of soil contains up to 6 billion microorganisms, says Australia's New South Wales Government. Soil is also a habitat for species including insects and fungi. Healthy soil supports other water, land and air environments and ecosystems through natural processes including water drainage and pollination – the fertilization of plants. (World Economic Forum, https://www.weforum.org/agenda/2022/10/what-is-regenerative-agriculture/).

Replication
(see also Reproduction and replication compared)
1. Production of copies of the genetic material (Rowe and Lafferty, 1993)
2. This term tends to be restricted to the duplication of informational macromolecules and of cells and subcellular organelles (Lawrence, 2008)

Replicators

See objects of selection.

Reproduction
(see also replication and compared)
1. Making a copy, a likeness, and thereby providing for the continued existence of species (Bonner 2009)
2. The process by which a living organism produces other organisms similar to itself (Rowe and Lafferty, 1993)
3. The process by which a living thing, whether plant or animal, gives rise to another of its kind (Guyer, 1963).
4. The crux of reproduction is that it occurs throughout the hierarchy of levels in biological organisation starting with the molecular and sub-cellular level of proteins and informational macromolecules (RNA and DNA) and proceeding through each of the levels in the spectrum of biological organisation.
5. Formation of new individuals (Lawrence, 2008).
6. Reproduction is the process by which life forms from viruses to monerans, protistans, fungi, plants and animals generate new individuals of the same kind, ensuring the continuity of life in their species. Reproduction can be asexual with one parent and identical offspring or sexual with two parents and genetically varying offspring (precising definition).

Reproduction and replication compared
Replication refers to the duplication of informational macromolecules by life forms (including viruses and prions whereas reproduction refers to the processes by which life forms give rise to new individuals of their kind (precising definition).

Reservoir host
(see host).

Resilience
Ability of a living system to restore itself to its original condition after being disturbed (Lawrence, 2008).

Retrotransposon
A mobile DNA sequence that can insert itself at a different position by using reverse transcriptase, compare with transposon (Passarge, 2007).

Risk
Means the likelihood of the occurrence and the likely magnitude of the biological and economic consequences of an adverse event or effect to animal or human health.
(https://www.woah.org/fileadmin/Home/eng/Health_standards/tahc/2018/)

Risk analysis

Means the process composed of *hazard* identification, *risk assessment*, *risk management* and *risk communication*. (https://www.woah.org/fileadmin/Home/eng/Health_standards/tahc/2018/).

Risk assessment
Means the evaluation of the likelihood and the biological and economic consequences of entry, establishment and spread of a hazard.(https://www.woah.org/fileadmin/Home/eng/Health_standards/tahc/2018/).

Risk communication
Is the interactive transmission and exchange of information and opinions throughout the *risk analysis* process concerning *risk*, *risk*-related factors and *risk* perceptions among *risk* assessors, *risk* managers, *risk* communicators, the general public and other interested parties.https://www.woah.org/fileadmin/Home/eng/Health_standards/tahc/2018/)

Risk management
Means the process of identifying, selecting and implementing measures that can be applied to reduce the level of risk. (https://www.woah.org/fileadmin/Home/eng/Health_standards/tahc/2018/).

RNA satellite
Plant viral satellite RNAs (satRNAs) are subviral RNA agents that depend on their helper viruses for replication and encapsidation/dissemination, and can be considered molecular parasites of plant viruses (https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/satellite-rna).

Routine
A customary procedure or regular course [FORM] for undertaking a task or activity [FUNCTION] (precising definition).

Science
1. Science is the pursuit and application of knowledge and understanding of the natural and social world following a systematic methodology based on evidence (Science Council; https://sciencecouncil.org/about-science/our-definition-of-science/).
2. The use of evidence to construct testable explanations and predictions of natural phenomena, as well as the knowledge generated through this process (National Academy of Sciences, 2008).

Scientific method
The rational **f**ormulation of hypotheses, collection of data, and testing of hypotheses against observations or experimental results that is the basis of the scientific approach to explaining natural phenomena (Lawrence, 2008).

Selection
See natural selection.

Selection pressure
The effect of any feature of the environment that results in natural selection, e.g. food shortage, predator activity, competition from members of the same or other species(precising definition).

Selective advantage
Any character that gives an organism a greater chance of surviving to reproductive age, breeding and rearing viable offspring (precising definition).

Semantics
The study of meaning in language and how meaning in language is created by the use and interrelationships of words, phrases and sentences (see Linguistics)(precising definition).

Semantic field
A set of words grouped by their related meanings and referring to a particular subject. A semantic field is a set of synonyms and related concepts. The keyword entries in thesauruses classify as semantic fields (precising definition).

Sequence space
Sequence space is a term from evolutionary biology and refers to ways and means for representing all nucleotide sequences that are possible for a particular protein, gene or genome (precising definition).

Solidarity
Solidarity signifies shared practices reflecting a collective commitment to carry costs (financial, social, emotional or otherwise) to assist others. Solidarity is seen as a practice and not merely as an inner sentiment or an abstract value that requires actions and that motivations, feelings such as empathy etc. are not sufficient to satisfy this understanding of solidarity, unless they manifest themselves in acts (Prainsack and Pruyx, 2011).

Species
1. Species are discrete populations of organisms (some of which are holobionts, see section 4.2.3) or sub-cellular and non-organismal entities such as viruses, viroids and prions (so-called semibionts, see sections 4.3.5 and 4.3.6) which share structural and functional characteristics. Some of these characteristics implement and control the exchanges (vertical or horizontal) and propagation of genetic material[107] as whole genomes through successive generations; thus creating barriers to reproduction and opportunities for reproduction that demarcate one discrete population from

[107] As explained in section 4.2.8, the genetic material of prions is protein not DNA or RNA.

another. Species contain subsets or subpopulations[108] with diverse capabilities that constitute variation.

2. Put simply, species are discrete populations of life forms possessing communal properties for reproduction.

3. Species are discrete populations of organisms (some of which are holobionts) or sub-cellular and non-organismal entities such as viruses, viroids, viusoids and prions, that share structural and functional characteristics. Some of these characteristics implement and control the exchanges (vertical or horizontal) and propagation of genetic material as whole genomes through successive generations and thus create barriers to reproduction and opportunities for reproduction that demarcate one discrete population from another. Species contain subsets or subpopulations with diverse capabilities that constitute variation (precising definition).

Spillover infection

Spillover infections occur when a population of susceptible permissive hosts for a particular infectious disease agent are exposed to transmission from a population of reservoir hosts infected with that agent (spillover as a descriptor attributable to David Quammen in a book *Spillover: Animal Infection and the Next Human Pandemic;* Brown, 2013).

Stress

1. Any stimulus or succession of stimuli of such magnitude as to disrupt the homeostatic mechanisms of an organism (Hoerr and Osol, 1956).

2. A consciously or unconsciously sensed threat to homeostasis, in which the response has a degree of specificity, depending, among other things, on the particular challenge to homeostasis, the organism's perception of the stressor and the perceived ability to cope with it (Goldstein and Kopin, 2007).

Stressor

A stimulus that causes stress (https://www.merriam-webster.com/dictionary/stressor).

Structure (form)

Structure: The arrangement or interrelation of all the [physical] parts of a whole (adapted from Webster's). A system or organization made up of interrelated parts functioning as an orderly whole (Rooney, 1999). Amalgamate as precising definition.

Form The way the physical components of a whole are organized (adapted from Webster's).

Subordinate concept (see concept hierarchy)

Superordinate concept (see concept hierarchy)

[108] The terms suprapopulation and infrapopulation have a particular use within the discipline of parasitology (Bush et al., 1997; Margolis et al., 1982) and are not apt for present purposes. A suprapopulation is all individuals of a species of parasite in all stages of development within all hosts in an ecosystem. An infrapopulation is all individuals of a species of parasite occurring in an individual host.

Susceptibility
Refers to the ability of an exposed individual (host) or group of individals (hosts) to resist infection and resist disease as a result of their biological makeup (Van Seventer and Hochberg, 2017).

Sustainable agriculture
The term ‘sustainable agriculture' means an integrated system of plant and animal production practices having a site-specific application that will over the long-term:

- Satisfy human food and fiber needs.
- Enhance environmental quality and the natural resource base upon which the agriculture economy depends.
- Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.
- Sustain the economic viability of farm operations.
- Enhance the quality of life for farmers and society as a whole.

(Legal definition in the USA according to 7 U.S. Code § 3103 – Definitions: https://www.nal.usda.gov/farms-and-agricultural-production-systems/sustainable-agriculture).

Symbiosis
1. The close and usually obligatory association of two or more life forms of different species living together, not necessarily to their mutual benefit (precising definition).
2. Often used exclusively for an association in which both partners benefit, which is more properly called mutualism (Lawrence, 2008).

System approach
Based on the principle that everything is interrelated and interdependent. A system is composed of related, dependent and interacting elements that, jointly, produce a unified whole. Adopting this approach, a system and its subsystems are studied in their interrelationships rather than in isolation and the system outputs are considered to be produced through joint efforts of subsystems. In a systems approach, attention is paid to the overall effectiveness of the system rather than the effectiveness of subsystems (FAO, UNEP, WHO, and WOAH. 2022).

Teleology
The philosophical view that natural events are goal-directed and pre-ordained, as opposed to the scientific view of mechanical determinism (Hickman et al., 2006).

Teleonomy
The term teleonomy was coined for use in biology to avoid notions of ‘natural theology’ and ‘vitalism’ that might be implied by teleology (Lennox, 1992). Teleonomy refers to purposefulness [purposiveness?] and goal-directedness of structures and functions as apparent in living organism*s* (precising definition).

Theory (in Science)

See also Laws

According to publications from the National Academy of Sciences of the USA, theories in science are intelligible as ‘well-substantiated explanations of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses’(National Academy of Sciences 1998, National Academy of Sciences, 1999) or ‘comprehensive explanations of aspects of nature that are supported by vast bodies of evidence such that they can be used to make predictions about natural events or phenomena that have not yet been observed’ (National Academy of Sciences, 2008). Theories can be refined in the light of new knowledge. The definition from National Academy of Sciences (2008) serves as a precising definition for the proposed ontology.

Theory of Evolution by Natural Selection

1. The theory of evolution [by natural selection] is a body of interconnected statements about natural selection and the other processes that are thought to cause evolution, just as the atomic theory of chemistry and the Newtonian theory of mechanics are bodies of statements that describe causes of chemical and physical phenomena [and can be used to make predictions about natural events or phenomena that have not yet been observed](adapted from Futuyma and Kirkpatrick, 2017).
2. The theory of evolution by natural selection is a well-supported scientific explanation for the diversity of life and proposes that populations of life forms from species to ecosystems evolve over time through the differential survival and reproduction of individuals with heritable traits that confer advantages in a given environment and which can be used to make predictions about natural events or phenomena that have not yet been observed (precising definition).

Thermodynamics

(Guided by The New Encyclopedia Britannica, Fifteenth Edition, 2007)

Systematic study of the relationships between heat, work, temperature and energy, now encompassing the general behaviour of physical systems in conditions of equilibrium or close to it. It is fundamental to all parts of the physical sciences and to the essential features of living systems.

A central consideration of thermodynamics is that any physical system, whether or not it can exchange energy or matter with its surrounding environment, will spontaneously approach a stable state(equilibrium) that can be described by specifying its properties such as pressure, temperature, or physical composition.

Entropy

1. Key concept in understanding how total energy remains the same when energy transforms from one form to another (see First Law). Ordered energy unlike disordered energy can be harnessed to do work. Entropy is a measure of this disorder and the energy unavailable for work.
2. A measure of the amount of energy in a physical system that cannot be used to do work.

Laws of thermodynamics

<u>Zeroth Law</u>: If two systems are each in thermal equilibrium with a third system, they are in thermal equilibrium with each other. This law establishes the concept of temperature and allows for temperature comparison between systems.

First Law (Law of Energy Conservation): Energy cannot be created or destroyed, only transformed or transferred. In a closed system, the change in internal energy is equal to the heat added to the system minus the work done by the system.
Second Law: In any energy transfer or transformation, some energy becomes unavailable to do work, often increasing the disorder (entropy) of the system. In an isolated system, entropy will either increase or remain the same, never decrease.
Third Law: As a system approaches absolute zero (0°Kelvin), its entropy approaches a minimum, often interpreted as zero. Absolute zero is theoretically unattainable, as removing the last traces of thermal energy is increasingly difficult.

Trade-off
An evolutionary change that increases fitness in one trait or context but causes a decrease in fitness in another trait or context (Stearns, 2014).
A balancing between two traits that occurs when an increase in fitness (survival and reproduction) due to one trait is opposed by a decrease in fitness due to a concomitant change in the second trait (Turner, 2014).

Transboundary animal diseases (TADs)
Epidemic diseases that are highly contagious or transmissible and have the potential for very rapid spread, irrespective of national borders, causing serious socioeconomic and possibly public health consequences; their control/management, including exclusion, requires cooperation between several countries (FAO, UNEP, WHO, and WOAH. 2022).

Transfer host
(see host).

Transmission
The communication or transfer of anything, especially disease, from one **host** or place to another. Transmission allows for infection or the implanting an infectious agent (microbe, virus or fungus) into the body of a host (precising definition).

Transport host
(see host).

Transposable genetic element
See Transposon.

Transposon
1. Transposons are transposable genetic elements or DNA sequences that possess the property of inserting themselves elsewhere on the chromosomes by a process called transposition. They are present in both eukaryotic and prokaryotic genomes. The simplest types of transposable element

are bacterial insertion sequences, which carry only the genes necessary for their own transposition (Lawrence, 2008). Larger bacterial transposons also carry genes for other functions, such as antibiotic resistance.
2. A DNA sequence with the ability to move and be inserted at a new location of the genome (Passarge, 2007).

Units of selection
See objects of selection.

Variation
(also variability, genetic variation and genetic diversity)
Phenotypic differences existing between individuals of the same species (other than those due to age and life cycle stage) and which reflect both genetic differences and the influence of the environment (precising definition).

Vector
(Disease vector)
A life form that carries and transmits an infectious pathogen to another living organism.

Vehicular language
A language used as a contact language between two groups who do not share a common native tongue nor a common culture (precising definition).

Vertical gene transfer
[Compare with horizontal gene transfer]
The transfer of genetic information from parents to offspring generation after generation (Klug et al., 2020).

Viability (viable)
For purposes of the conceptual framework or ontology for theory of evolution by natural selection, viability is depicted for organisms, as the capability for life, being alive or living. For biological entities such as viruses and prions viability is depicted as the capability for existing and executing life cycles based on propagation within organisms and transmission among organisms. Viability does not imply ‘vitalism’ or the contention that the origin and phenomena of life depend on forces or principles distinct from chemical or physical forces (precising definition).

Virion
The extracellular life cycle stage of viruses that mediates **infection** in hosts and **transmission** from host to host and which consist of informational macromolecules (DNA or RNA in various forms that constitute a genome), a capsid or protein coat and sometimes an envelope or lipoprotein outer covering (precising definition).

Viroids
Small single-stranded and circular RNA macromolecules that infect plants (mainly angiosperms) and cause disease. Viroids differ from viruses in having no protein coat (precising definition).

Virulence
Used as a quantitative expression of the disease-producing potential of a pathogenic agent (Bennett et al., 2020).

Virus
Viruses are submicroscopic infectious agents, non-organismal biological entities and obligate intracellular symbionts with life cycles entailing capabilities and structures for **reproduction** within **hosts** and **transmission** between hosts. The **virion** which consists of informational macromolecules (DNA or RNA in various forms that constitute an evolvable **genome**), a **capsid** or protein coat and sometimes an envelope or lipoprotein outer covering is the extracellular stage of viruses that mediates **infection** in hosts and **transmission** from host to host. Viruses reproduce within hosts by employing information encoded in their genomes to harness intracellular processes for transforming matter and energy (precising definition).

Virusoid
Circular single-stranded RNA(s) dependent on viruses for replication and encapsidation. The genome of virusoids consist of several hundred (200–400) nucleotides and does not code for any proteins. Virusoids are essentially viroids that have been encapsulated by a helper virus coat protein (https://en.wikipedia.org/wiki/Virusoid).

Vector
An insect or any living carrier that transports an infectious agent from an infected individual to a susceptible individual or its food or immediate surroundings (FAO, UNEP, WHO, and WOAH. 2022).

Vector-borne diseases
Illnesses caused by parasites, viruses and bacteria that are transmitted by vectors (FAO, UNEP, WHO, and WOAH. 2022).

Waterborne diseases
Illnesses caused by parasites, viruses and bacteria that are transmitted by water (FAO, UNEP, WHO, and WOAH. 2022).

Zoonoses (zoonotic diseases)
Infectious diseases that can be spread between animals and humans, by food, water, fomites or vectors (FAO, UNEP, WHO, and WOAH. 2022).

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